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ELEMENTS OF AGRICULTURE

FREAM'S

ELEMENTS OF AGRICULTURE

A TEXTBOOK PREPARED UNDER THE AUTHORITY
OF THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND.
ORIGINALLY EDITED BY THE LATE W. FREAM, LL.D.

FOURTEENTH EDITION

Edited by

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PREFACE TO THE FOURTEENTH EDITION

THE thirteenth edition of Fream's Elements of Agriculture appeared in 1949. During the past twelve years it has been twice revised, and reprinted several times. This new, fourteenth edition follows the same general pattern, but has been enlarged and brought thoroughly up-to-date by Dr. D. H. Robinson and a team of collaborators including: D. M. Allen, Ph.D.; C. J. L. Baker, F.R.I.C.; G. D. H. Bell, Ph.D.; A. J. Brookes, M.A.; C. Culpin, M.A.; S. Culpin, M.Sc.; W. Morley Davies, M.A., B.Sc.; A. Eden, Ph.D.; M. Eddowes, M.Sc.; G. H. A. Edwards, B.A.; J. Halliwell, N.D.P.; R. Holliday, B.Sc.; J. R. Hopkins, B.Sc.; G. Pearson Hughes, B.Sc.; A. J. Langdon, M.A.; D. Mackney, B.Sc.; H. C. F. Newton, B.Sc.; E. J. Nichols, Ph.D.; H. H. Nicholson, M.A.; J. J. North, B.Sc.; J. W. Reid, N.D.A.; K. Russell, B.Sc.; E. R. Taylor, Ph.D.; J. F. H. Thomas, M.Sc.; D. B. Wallace, M.A.

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Chapter I

THE SOIL

The scientific study of the soil embraces a great deal more than a series of chemical analyses, and consequently it is important at the outset to appreciate the distinction to be made between soil as a *material*, and soil as a *natural body*. The difference between a handful of dry earth in the laboratory and the undisturbed soil in the field is just as great as between a handful of hay and the living, uncut grass. Fundamental knowledge of the soil must be sought in three main directions : the chemical, the physical and the biological. Questions relating to the nature and proportions of soil material generally require the chemical approach ; considerations such as the movements of water in soil, and the manner in which soil material is built up to form the soil body in the field, are examples of soil physics ; whilst the biological aspects include studies of soil bacteria, fungi and animals, and the relationship of soils to their natural vegetation. These represent the more significant features about soil in relation to the business of farming, and they will now be considered further.

SOIL FORMATION

Many quarry faces show on inspection a gradual transition between the original solid rock and the surface soil, such as depicted in Fig. 1. As the eye travels upwards cracks and fissures can be observed, which grow more definite until separate masses of rock are apparent. These become smaller, and the fissures more numerous and more open, until soil appears between the rock fragments and the general condition is brashy. At a still higher level the predominant constituent of the mass is obviously soil, and finally the top few inches become darker in colour and are found to contain the root systems of the herbage growing on the surface, with other accumulations of organic matter. Throughout the transition the significance of the original rock and its more obvious characteristics can be readily observed, and it will be appreciated that the rock constitutes the parent material from which the soil has developed through the action of various natural agencies such as climate and vegetation. Any source of information concerning the various kinds of parent materials distributed throughout the country is obviously of considerable importance in the study of soil ; it is primarily in this respect that some understanding of geology, the science which is concerned with the origin and nature of the earth's crust, is of value to the agriculturalist.

Geology and Soils. The geological sequence of events in the earth's history was probably as follows. Presuming the earth to have been formerly a molten mass at high temperature, the first formed rocks arose from the cooling down of the surface with the development of a hard outer crust with a still molten interior. These rocks, because of their association with heat and fire, are known as *igneous* rocks. Subsequently further igneous rocks were, and are still being, formed by volcanic eruptions. Typical of igneous rocks are granite and basalt, which are hard and fairly resistant to the weathering effects of climate ; for this reason, and also because of their often volcanic origin, they are generally associated with mountainous areas.

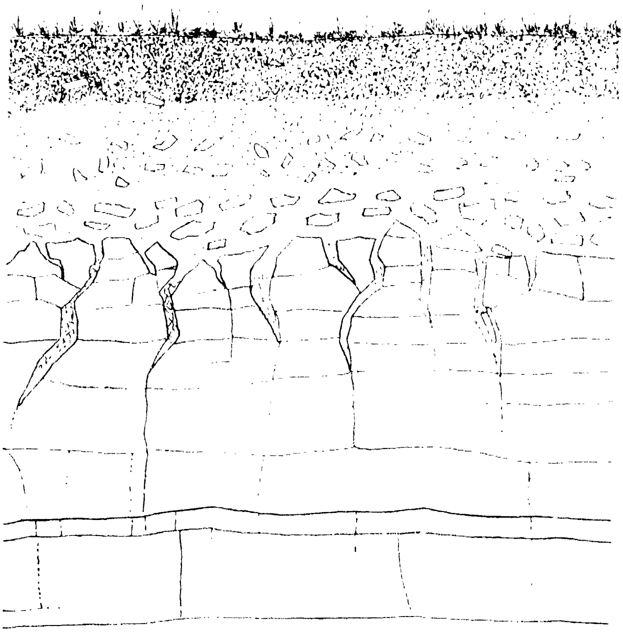


FIG. 1.—DIAGRAMMATIC REPRESENTATION OF SOIL FORMATION FROM UNDERLYING ROCK.

Once a shell of igneous material began to form, local variations of temperature would provide the beginnings of a climate, and the concentration of water in low-lying areas would establish seas and lakes. From time to time, however, gigantic earth movements brought about an entirely new geography and a redistribution of climate, thus instituting new geological eras. During every such era the natural agencies would be at work on exposed rock surfaces, weathering them down to masses of broken material which might be transported and deposited elsewhere to form new rock masses called *sedimentary* rocks.

Sedimentary rocks are almost all composed of small rock particles which have been carried along by rivers and deposited on the floor of seas, lakes and estuaries. These sediments later become compressed by the weight of overburden and cemented together into new rock forms ; included amongst these are sandstones, shales and clays. A less-abundant but none the less important group is of organic origin ; that is to say, its constituents have been accumulated as the result of living organisms. The most prominent members are chalks and limestones, composed of the shells of marine organisms of various sizes, and coal which has resulted from preserved plant remains. It will be noted that clay is in the geological sense classed as a rock when it constitutes a deposit laid down in a well-defined geological era. The earlier formed sedimentary rocks were later themselves partly weathered and transported to form fresh deposits in subsequent eras each of which may represent a span of millions of years ; thus a whole sequence, formed throughout geological time, has been traced by geologists and embodied in a geological classification of the earth's crust.

In geologically more recent times events during various " ice ages " resulted in vast quantities of surface material being pushed across land areas in front of moving glaciers and deposited where the latter finally melted. Thus in certain parts of the country, formerly subjected to the action of glaciers, extensive sheets of surface material may bear no relationship to the underlying sedimentary or igneous rocks ; these deposits are styled as *glacial drift.*

The distribution of igneous rocks, sedimentary rocks, and drift throughout Great Britain, has been studied by geologists and depicted upon geological maps ; published information, in the form of district memoirs, is also available regarding the actual nature of the various deposits concerned.

The Composition of Rocks and Minerals. Igneous rocks, as has already been indicated, appear to have been formed by the cooling of original molten material. During this process the various chemical elements present become formed into various distinctive minerals. A mineral may be defined as a rock component having a definite chemical composition and a definite crystal structure. Thus a study of the mineral composition of igneous rocks, and of the manner in which they are decomposed by weathering, affords some idea of the kinds of materials which ultimately form the basis of soils.

The make-up of igneous rocks, in general, includes such chemical elements as oxygen, silicon, aluminium, iron, calcium, sodium, potassium, magnesium, titanium, carbon, phosphorus and sulphur, in the form of various minerals. The approximate percentage proportions of these elements present in the earth's crust are oxygen 50, silicon 25, aluminium 7, iron 5, calcium 3·5, sodium 2·5, potassium 2, magnesium 2, titanium 0·5, carbon 0·1, phosphorus 0·1 and sulphur 0·06 per cent ; the actual amounts, however, vary for different types of rock, a factor of significance in relation to the derived soils. Those classes of igneous rocks in which the proportion of silicon, which is non-metallic and therefore acidic, is greater than 25 per cent are known as *acidic* rocks ; where the silicon content is less than 25 per cent, together with a consequent increase in the proportions of calcium, sodium, potassium or magnesium, which are metallic and therefore basic or non-acidic, the term *basic* rock is applied. Granite is an example of an acidic rock, basalt of a basic rock.

If a freshly broken piece of granite be examined it is seen to consist of large white or pink crystals together with much smaller dark or black crystals, firmly set in an irregular mass of whitish crystalline material. The large white or pink crystals represent a mineral known as felspar, which is a potassium (or calcium) alumino-silicate ; the small black crystals are the mineral mica, which contains in addition to alumino-silicates appreciable proportions of iron and magnesium. Mica is thus one of the so-called ferro-magnesian minerals. The whitish crystalline mass in which the other crystals are embedded is a mineral known as quartz ; quartz is a crystalline form of silica, or silicon oxide, a compound composed of silicon and oxygen. It is the presence of this high proportion of quartz which makes granite an acidic rock, and this acidic tendency is transmitted to soils derived from granite. Basalt differs chemically from granite principally in the elimination of quartz, its place being largely taken by ferro-magnesian minerals.

Since sedimentary rocks are in the first place derived from igneous rocks it is not surprising that they are often composed of some of the minerals already mentioned ; owing to the processes of weathering and transportation which have occurred, however, the proportions of each present have been altered and the range considerably restricted. Thus most sandstones have a predominant content of quartz and are more accurately known as quartzose sandstones ; if mica or felspars, reduced to the size of sand particles by weathering, are present in appreciable quantities the sandstones are known respectively as micaceous sandstones and felspathic sandstones. The reason for the predominance of quartz in the sedimentary sandstones will be more fully appreciated after a consideration of the mechanism of weathering.

The Processes of Weathering. Weathering is the result partly of the operation of physical forces and partly of chemical reactions on original rocks. Variations in temperature produce expansions and contractions of the rock minerals and, since the different classes of minerals respond to differing extents, stresses and strains are set up in the rock as a whole, causing it to crack and shatter. Water enters these cracks in the rock mass and, if freezing occurs, the expansion of the resultant ice produces an enormous disruptive force. The result is that the rock is more widely split, and it may finally shatter down to a deposit of angular fragments. The natural agencies already mentioned, such as running water or glaciers, may subsequently transport the fragments, grinding them together and against the surfaces over which they move in the process, thus carrying disintegration still further. All these actions have as their primary effect simply the reduction of a single mass of rock to a large number of small rounded particles which may ultimately collect to form a deposit of sand or sandstone. Since there has as yet been no alteration in chemical composition the processes so far outlined constitute what is termed *physical* or *mechanical* weathering.

Concurrently with physical weathering, *chemical* weathering is also taking place. Here the most potent force is the action of water which in the passage of time very slowly dissolves certain of the materials of which the rock particles are composed and sets up chemical reactions on their constituents. The solvent action of water is considerably enhanced by the fact that rain in its passage through the atmosphere acquires a certain amount of carbon dioxide and becomes weakly acidic ; this solvent action is increased by further contact with carbon dioxide as the water percolates through the surface soil. The general trend of the reactions which take place is the splitting up of some of the complex minerals in the rocks, removing certain of their ingredients dissolved in the drainage water and leaving others behind as insoluble residues. These decompositions are very complicated because of the considerable number of varying factors involved, but the final result will be largely determined by the nature of the original rocks and the prevailing climatic conditions.

The issues may be more clearly understood by considering specific cases. When granite weathers chemically it is found that its quartz is highly resistant and is very little affected ; the felspars lose their potassium as soluble potassium carbonate, leaving behind a residue of hydrated alumino-silicate, which is a variety of clay ; the mica similarly loses soluble constituents, and clay-like residues may accumulate, often coloured brown or red by the liberated iron compounds. Thus the weathering of granite results broadly in the formation of stones, sand and clay, which may go to form a soil on the spot, or may be transported away to become the basis of various sedimentary sand and clay deposits, which may in their turn be subjected to further weathering in a subsequent period.

It will be appreciated that these weathering processes still continue after a soil has been considerably developed from its parent material. They are, in fact, the means by which mineralised chemical substances are continuously being liberated as plant food. This ultimate weathering will be referred to later in the chapter, in relation to soil classification.

Biological Factors in Soil Formation. While the processes of weathering are producing the mass of mineral particles of which most soils are mainly composed, various forms of life have developed on and in the soil, and they in turn have exerted important effects. The most obvious of these living organisms are plants whose stems and leaves are supported in the air by means of an underground root system. Plants normally develop from seeds buried in the soil which, given suitable surroundings of oxygen, moisture and warmth, germinate and produce both a root and a shoot. If the supply of food materials in the seed suffices to enable the shoot to reach the surface by penetrating the upper layer of the soil, the shoot produces small green leaves which assimilate carbon dioxide from the air. At the same time the rootlet absorbs moisture containing small quantities of nutrient material derived from the mineral matter of the soil. The substances thus absorbed—the carbon dioxide, the water and the mineral substances—are, with the aid of energy derived from sunlight, elaborated by the plant into complex organic compounds such as starch, cellulose and lignin with which the plant builds up its structure and makes growth. When the plant dies it decays, and from its remains a decomposition product known as *humus* may be formed in the soil.

In addition to the plants visible upon its surface, the soil teems with living organisms of many different kinds, from earthworms and insects down to microscopic forms such as fungi and bacteria, all of which play their part in the development of the soil complex. In the past half-century micro-organisms have been the subject of much research work so that today soil microbiology represents a very important branch of soil studies. It is now known that many micro-organisms are dependent for their food upon the organic matter accumulated by plants: this food they obtain by attacking and decomposing plant material. Humus is a by-product of processes of this type. Other micro-organisms have the ability to assimilate atmospheric nitrogen, which they accumulate in their own structures and which may ultimately become available as plant food.

As well as enriching the soil with various forms of organic matter, living organisms undoubtedly further the general processes of weathering soil minerals. The mechanical effect of plant roots in disrupting rocks by penetrating into cracks and fissures is fairly well known; less obvious are the slow grinding effects which earthworms and kindred creatures exert on soil mineral particles. The excretions of various organisms may also assist in chemical weathering.

It is to be expected that what might be termed the living or active part of the soil would be the surface layer, and examination generally shows this to be the case. The content of organic matter, insect life, bacteria and plant roots fairly rapidly decreases with increasing depth. Consequently, from the point of view of its employment for crop production, the top soil has very different properties and capabilities from the subsoil, a fact of great importance in connection with such questions as the depth of ploughing, the value of subsoiling and the most suitable system of cropping.

THE PHYSICAL PROPERTIES OF SOIL

So far the soil has been considered from the point of view of its development and of the natural phenomena which influence this. It is necessary now to consider the composition and properties of the mineral and organic portions: the internal conditions of moisture, temperature, and aeration, which constitute *the soil climate*: and the nature and functions of the associated living organisms.

Texture and Soil Material. Texture is the property which largely determines the ease or difficulty of cultivations, and walking on the land is one of the most impressive ways of appreciating its significance. During wet weather we have at one extreme, slippery, sticky soils where walking is difficult owing to tenacious accumulations on the feet, and in which moisture is obviously excessive; at the other extreme are non-plastic soils, which exhibit no adhesive tendencies, and on which walking is comparatively easy and where conditions are dry underfoot. By contrast, in times of drought the first set of conditions is replaced by those of hard clods, or of a rock-like surface traversed by numerous cracks, while the latter give place to a loose, dry, friable condition in which the individual soil particles show little tendency to cohesion. These examples of soil texture are due primarily to the nature and quantity of the various mineral particles present. If a handful of ordinary soil be examined closely by the aid of a pocket lens, it can be observed that the mineral particles are of all shapes and sizes, diminishing from obvious pebbles. If a little of the soil is moistened and rubbed between the fingers the gritty nature of the larger particles is revealed, even when to the eye their proportion is extremely small ; at the same time it may be realised that the greasy feel and stickiness of a soil are attributes of its finer particles. In ordinary parlance the terms " sand " and " clay " imply some of these impressions of grittiness and stickiness, the former being responsible for uncohesive and loose conditions and the latter for tenacious and plastic qualities.

Size of Particles. To give precision to such terms, and to facilitate analytical comparisons between different soils, a convention has been established with respect to particle size. On this basis, particles with a diameter exceeding 2 mm. are considered as stones, whereas those particles of less diameter than 0·002 mm. are considered to have the properties of clay. In the natural condition, as has been previously mentioned, soil particles may not all be separate from one another but may be aggregated into crumbs and clods of varying sizes. For the purpose of analysis of particle sizes any soil sample must undergo a preliminary treatment to destroy the crumbs ; when this is accomplished the larger particles can be removed by sieves of appropriate dimensions. The smaller particles, however, can pass through the meshes of the finest sieves practicable for this work, so recourse must be made to another method of separation. This is based on the fact that particles of the same material, but of varying sizes, sink through a liquid medium such as water at different rates, dependent upon their diameters. By combining the two processes of sieving and sedimentation any soil sample can be divided into a series of arbitrary fractions whose limits are set out below.

Fraction.	Diameter of Particle.
Gravel	1 cm. 2 mm.
Coarse sand	2–0·2 mm.
Fine sand	0·2–0·02 mm.
Silt	0·02–0·002 mm.
Clay	less than 0·002 mm.

The process of separating the mineral portion of a soil into these fractions is known as a *mechanical analysis*.

The differing textural properties imparted by stones, coarse sand, fine sand and silt are largely the result of their diminishing particle size and the particles may in fact merely represent successive stages in the degree of sub-division of an original rock mass. Clay, on the other hand, as has already been indicated, is derived from the chemical decomposition of larger mineral particles and therefore it can impart additional textural effects which are partly due to its changed chemical nature as distinct from the further reduction in particle size.

Specific Surface. The effect of "specific surface" of soil particles is, however, of very great importance and merits a more detailed explanation. If a cube with 1 ft. sides be considered, the total area of its six faces is 6 sq. ft. If this cube is now sliced up into smaller cubes each with sides of 0·1 ft. there will be 1,000 small cubes and the total area of each cube will be 6 × 0·1 × 0·1 = 0·06 sq. ft. Since, however, there are 1,000 of them their total area will be 1,000 × 0·06 = 60 sq. ft.; thus by sub-dividing the material its total surface area has been increased. The more finely the material is sub-divided the greater will be the total surface area for a given quantity. It has been computed that the total surface area of the particles of a cubic foot of sand is 6,000 sq. ft., whilst that for a cubic foot of clay is 100,000 sq. ft.; it is therefore the clay fraction which is responsible for by far the greatest proportion of the internal surfaces of soils. If these surfaces are visualised as covered by, and retaining, a uniform film of moisture, the connection between the water-holding powers of the various-sized soil fractions begins to reveal itself.

THE PROPERTIES OF CLAY

Apart from the retention of water by the surfaces of all the particles of a wet soil, water can also be held internally by the clay particles. This special capacity for water absorption causes clay particles to expand on wetting and shrink on drying. Thus wet clay soils tend to present a barrier of tightly packed particles impervious to the passage of surface drainage water, whereas a dry clay soil is permeated by wide and deep cracks. Furthermore, since clay particles have the special property of cohesiveness, a mass of drying clay will tend to form clods between the fissures. This can be contrasted with coarse sand which shows practically no cohesion and water absorption, and allows free drainage; and with fine sand which does show some cohesion on drying, but is easily crumbled and permits free movement of water. Silt more closely resembles clay in its physical properties.

As has already been indicated, the great reactivity of clay is not due entirely to its extensive internal surfaces. The clay fraction includes hydrated alumino-silicate compounds that have been formed from the decomposition of minerals present originally in unweathered rocks. Certain of these compounds have themselves characteristic crystalline structures and are known as "clay minerals"; amongst these can be mentioned kaolinite, beidellite and montmorillonite. In addition to recognisable minerals, such as those mentioned, there are also present in the clay fraction substances that are chemically reactive but of indefinite composition, together with hydrated alumina and free hydrated iron oxides which confer yellowish or reddish soil colours.

Colloidal Behaviour. Many of the properties exhibited by clay are characteristic of a class of substances known as *colloids*, which are substances of extremely small ultimate particle size often showing considerable affinity for water. An important feature of colloids is the ability of their particles to aggregate into larger composites (flocculation) or to be dispersed into separate ultimate particles (deflocculation) according to the surrounding conditions. In the presence of a sufficient concentration of calcium a clay will tend to become flocculated, thus increasing its particle size and consequently decreasing its surface area and surface retention of water ; under conditions of acidity on the other hand a clay will tend to deflocculate, thus decreasing its particle size and increasing its imperviousness. This has important practical implications in that drainage, aeration and ease of cultivation in a clay soil can be appreciably increased by adequate liming whereas, in the absence of lime, acidity induced by carbonic acid will tend to degrade the physical conditions. It is in this respect that clay shows important differences from silt which, although exhibiting the properties of plasticity and cohesion, is not sufficiently colloidal to be flocculated into an agriculturally more desirable condition by liming.

Base Exchange. Clay is potentially of an acid character and the clay complex behaves in many respects as a weak insoluble acid ; thus it can combine with various basic (non-acidic) substances to form neutral compounds. The principal soil base in the British Isles is lime (calcium oxide). When a clay has combined to its fullest extent with bases it is said to be " base-saturated ". If insufficient bases are present the clay will make up the deficit by combining with hydrogen derived from soil acids and will reassert its acidic tendencies. Normally a neutral clay is a predominantly calcium clay, with smaller amounts of magnesium, potassium and sodium ; an acidic clay is largely a hydrogen clay. These bases and hydrogen are exchangeable, one for another. Thus if an acidic clay is limed, calcium is taken up by the clay and hydrogen is displaced into the soil solution. Similarly, if sulphate of ammonia is added to a calcium clay, ammonium (a base) is taken up by the clay and calcium is displaced to form soluble calcium sulphate, which is subsequently lost in the drainage water. This phenomenon, which is characteristic of many colloidal substances, is called *base exchange* ; the ability of a given quantity of clay, or soil, to retain exchangeable bases is called its " exchangeable base capacity ". It will therefore be appreciated that two main forms of calcium can exist in a soil, namely calcium directly combined with the clay (exchangeable calcium) and calcium in the form of calcium carbonate, which is not at the time chemically combined with the clay but which may form a potential reserve, later to be taken up as exchangeable base material.

Thus in addition to conferring upon a soil its water-holding capacity, clay is also to a considerable extent responsible for the retention of various essential plant nutrients and soil improvers such as calcium, potassium and magnesium.

THE ORGANIC MATTER OF THE SOIL

Although not included as one of the components of texture, particular emphasis must be placed upon soil organic matter as having an important effect upon the physical properties of soils. Soil organic matter can be considered as (*a*) undecomposed organic matter, and (*b*) decomposed organic matter or humus. In the first category are included recognisable plant remains such as fragments of roots, stems and leaves; in the second category come dark-coloured, amorphous materials, not readily distinguishable from the main soil mass, which are collectively known as *humus*. It is a common error to regard soil organic matter and humus as being identical, but such is far from the case. It is more accurate to recognise two separate classes, firstly " undecomposed organic matter ", and secondly " humus ", which is derived from the former through decomposition by soil micro-organisms.

Humus. The physical properties of the two classes are notably different. For instance, when straw, old turf, freshly made strawy farmyard manure, etc., are ploughed under they tend to prevent the soil particles from combining with one another; in other words, undecomposed organic matter keeps the soil " open "; this is desirable in heavy land but rarely so in light land. Humus, on the other hand, because of its colloidal nature, has those properties of water absorption and base exchange which have already been indicated in relation to clays. Humus can thus impart these desirable qualities to sandy soils, in which they would otherwise be deficient. Furthermore, humus has the property of facilitating the formation of soil crumbs, a function which it can best fulfil when endowed with an appreciable content of exchangeable calcium. The precise mechanism whereby humus enables crumb development is not clearly understood, but it can be considered as forming envelopes of colloidal material which enclose a number of individual soil particles and retain them distinctively from other similar units. Humus, by giving light soils enhanced water-holding and base capacities, and by giving heavy soils a crumb structure which increases porosity and aeration, is consequently an indispensable factor in soil fertility.

Humification. The chemical functions of humus are obscure, as a brief consideration of its mode of formation will indicate. Soil organic matter may decompose either by oxidation or by humification. Oxidation can be regarded simply as akin to burning, in which the organic matter is dissipated as carbon dioxide and water, leaving a small mineral residue; it is caused by certain micro-organisms and favoured by moisture, warmth, absence of undue acidity and, above all, by a good supply of air. In these circumstances, which are to be found in light, well-drained soils, and under arable conditions, organic matter can disappear very quickly.

Whilst oxidation is destructive, humifying processes are by contrast conservative in their effects.

The commonest kind of humification is an anærobic humification which takes place in the absence of, or with a restricted supply of air. Such conditions are outstanding in water-logged areas, but even in well-drained soils there are times when there is a sufficiently high moisture content and enough compaction for anærobic conditions to be brought about. Humus is derived largely from the fibrous component of plant tissues, called lignin, combined, through the activities of specific micro-organisms, with nitrogenous material obtained partly from nitrogen compounds already existing in the soil: consequently, when fresh organic matter is ploughed-in the level of readily available soil nitrogen may be reduced whilst humification is proceeding.

Another important factor in humification is that of base status ; in the presence of lime the humus formed will be a calcium humus with properties similar to calcium clay ; it is called " mild humus ". But, in the absence of lime, such as occurs on dry heath, pine forest, upland moor, etc., a different product known as " raw humus " results. Furthermore, the mineral content of soil organic matter may vary considerably according to the class of plant material from which the organic matter has been derived. If the original plant material was a product of fertile land its considerable content of calcium, potassium, phosphorus, etc., will be ultimately conveyed to the soil, which becomes enriched in both humus and mineral matter. If, however, the original plant material was itself of low mineral status, then it can do little in this respect ultimately to improve the soil, and its only contribution can be to provide organic matter for possible humification ; its main effect on the soil will probably be the long-term one of physical betterment. It should thus be clearly understood that organic matter is not necessarily the same thing as humus, and that neither is necessarily synonymous with fertility. For example, if an old phosphate-deficient pasture is ploughed-in, succeeding crops will be unsatisfactory in the absence of phosphate manuring in spite of the abundance of organic matter, a state of affairs which caused much disappointment during the war-time ploughing campaign.

SOIL STRUCTURE

Everyone accustomed to handling or cultivating soil will have noticed that the smallest particles tend to stick together in lumps which may show great resistance to further breakdown. A soil in which these aggregates have been fully broken down is said to be " dispersed " ; energetic chemical and physical treatment is normally necessary to achieve this. The study of the size grades of dispersed soil particles gives information about soil *texture* and by contrast the study of the aggregates themselves, their nature, stability and size grades gives information about soil *structure.*

The study of soil structure is of importance in practical cultivation and the more intensively the land is cropped the greater will be the importance of maintaining a good structural condition. Tillage operations in general, the trampling of stock, the passage of heavy implements and the impact of rain on bare ground all tend to harm the soil so far as its structure is concerned. A soil of good structure will be well drained and aerated, will provide a good medium for vigorous root growth, and will be resistant to harm done by necessary tillage operations and will tend to restore itself quickly to a satisfactory condition after it has been disturbed.

The unit of study in soil structural observations is the *ped* ; this is the natural aggregate formed in the soil and is contrasted with terms such as " clod " or " fragment " which refer to aggregates imposed by tillage implements and other external forces. The factors which should be noted are the extent to which the soil is aggregated into peds and the stability of the peds in the presence of conditions which tend to break them down. Other factors are the size and shape of the peds and the nature of their surfaces. Peds which are stable and persistent show faces that are well formed, and which are usually smoother than the interior when the ped is broken across ; they may also be of a different colour.

The shape of peds is important and a useful classification can be made as follows. Platy—with greater development of horizontal faces; prismatic—with vertical faces developed to a greater extent than the horizontal ; blocky—with roughly equal development of horizontal and vertical faces. Of these, blocky structures are the most widespread ; prismatic structures are most frequently found in clay subsoils ; platy structure is somewhat less often encountered. The term blocky structure needs further subdivision. This can be " angular blocky " when the faces tend to be casts of the opposing faces, and " spheroidal " when the surfaces are curved and rounded showing little or no accommodation to the adjoining faces. When " angular blocky " structure is well developed the peds have sharp interfaces and vertices ; when some of these are rounded, the term " subangular blocky " is used. Spheroidal structure may be " granular " if the peds are relatively non-porous or " crumb " if the peds are porous.

Crumb structure is by no means a frequently occurring condition, but it is found in the topmost layers of old permanent grass where the influence of numerous rootlets and the presence of insects and fungi has produced a layer containing rounded, spongy aggregates of this type. While it persists it forms an excellent medium for plant growth.

Structural defects in the soil are particularly evident on newly restored land after industrial working has taken place. On this type of land proper growth of crops cannot be obtained by use of manures and fertilisers alone however generously these are applied. The land tends to be waterlogged in winter, and cracked and parched in summer owing to poor movement of water through the soil. Aeration is poor and erosion can often be serious on sloping ground.

For scientific work calling for an exact recording of changes in structure taking place under particular systems of husbandry, attempts have been made to devise laboratory methods of measuring soil properties associated with soil structure. This is not an easy task owing to the complex nature of the phenomena, and no fully satisfactory methods have yet been generally accepted. Three factors are involved in these measurements. (1) The strength of the peds and their resistance to dispersive treatment. (2) The particle size grades of the peds as they are found in the soil. (3) The extent and nature of pore space, that is of the space both between one ped and the next and within the ped itself.

SOIL MOISTURE, AIR AND TEMPERATURE

Reference has already been made to various grades of soil moisture, including the moisture held by surface tension round the surfaces of soil particles, and the moisture absorbed internally by the clay-humus complex. Since, however, water supply is probably the most important factor in deciding the cropping abilities of a soil, the subject merits further consideration.

Moisture. The two categories of soil moisture referred to above are sometimes known as *capillary* water and *imbibitional* water : to these may be added a third, water actively draining through the soil and known as *gravitational* water. Given the same distribution of rainfall the proportions of these in different soils will depend upon the factors already mentioned, i.e. size of particle, amount of pore space and quantity of absorptive colloidal material present. Assuming the soil to be porous and the rainfall sufficient, the soil will ultimately become saturated with imbibitional and capillary water—the amount of which is termed the " field capacity " of the soil—and the surplus or gravitational water will drain downwards. Ultimately it will come to rest in a saturated underground zone known as the regional water table, the general level of which is indicated by the level of valley streams, lakes and wells.

It was formerly considered that capillary water could rise up to the surface from the water table, following a period of surface evaporation and serve as a source of moisture for crops, providing that the soil particles were pressed close together to form narrow conducting tubes ; and also that this capillary rise could then be checked and its loss by evaporation prevented by maintaining a loose open surface. On these assumptions the water-conserving effects of rolling and mulching were explained. Modern soil investigators now consider that capillary water is unlikely to rise above the water table for more than 5 or 6 ft. at the most, and they consider that the cultivations mentioned are effective mainly because they suppress weeds. It seems therefore that in many soils crops must rely, during periods of drought, mainly upon the water held at and in the soil particles themselves, since the soil surface may be many feet above the influence of the water table. Under these conditions the imbibitional and capillary water of the subsoil assumes considerable importance since it is more protected from evaporation. This emphasises the outstanding significance of certain factors of soil management. A satisfactory humus content should be developed in the surface soil so as to maintain the field capacity for moisture at the best possible level. Good drainage conditions should be ensured, including those induced by humus and lime, and those brought about by surface and under draining when necessary, so that plants may be encouraged to root as deeply as possible even at times when the soil tends to be water saturated, for a common cause of drought failure is the shallow rooting enforced upon crops by seasonal soil water-logging. Finally, whenever possible, root penetration to the subsoil should be aided by deep cultivations, sub-soiling, etc.

Air. The amount of air present in the soil will depend upon both the pore space, including the spaces between crumbs and particles and the spaces inside crumbs, and the moisture content. In an ordinary dry soil the pore space may amount to as much as 50 per cent of the total volume, but will be considerably less under wet puddled conditions. In composition the atmosphere within the soil differs from the external atmosphere in two important respects ;

first, it is usually saturated with water vapour, and second it contains a much higher proportion of carbon dioxide. Whereas normal air has a carbon dioxide content of about 0·03 per cent, that of the soil is often over 1 per cent. This increase originates from the respiration of plant roots and from the activities of soil micro-organisms in decomposing organic matter ; it consequently varies from soil to soil and from season to season. The carbon dioxide thus formed dissolves in the soil moisture to form carbonic acid which, as indicated previously, reinforces the dissolving action of the water on mineral matter and thus plays an important part in rendering available plant nutrients.

Temperature. The outstanding consideration concerning soil temperature is not so much the daily and seasonal variations, which in a general way are related to atmospheric temperatures, but rather the rapidity with which a soil assumes higher temperatures in the spring consequent upon the removal of surplus winter rainfall by drainage and evaporation. It takes ten times as much heat to raise a given quantity of water through one degree of temperature as it does the same weight of dry soil, and it takes over 500 times as much heat finally to evaporate that water as water vapour. It follows that in a soil of high moisture content a very considerable proportion of the heat absorbed from the sun and from the atmosphere is used up in evaporating water when it might otherwise, under drier conditions, have been used in warming the soil. The removal of surplus water by adequate drainage is therefore a very important feature in inducing a more rapid rise in soil temperatures in the spring. Another important temperature factor is the aspect of the soil ; a soil facing to the south will receive a greater intensity of the sun's rays and will therefore warm more rapidly than a similar soil with a northern aspect. The colour of the soil is also not without significance, since dark surfaces are more effective in absorbing heat from the sun than are other shades. On the whole, therefore, " early " soils are usually light textured and of southern aspect, whereas conspicuously late soils under the same range of climatic conditions are the northward-facing and badly drained heavy loams and clays.

THE CLASSIFICATION OF SOILS

The development of any branch of knowledge based upon scientific research can generally be traced in the increasing precision of its terms of reference, for it is a fundamental requirement of any pursuit claiming to be scientific that all its exponents shall mean precisely the same things when they use the same terms. Soil classification in its essentials simply means giving various distinctive classes of soils suitable names and descriptions, so that when these particular terms are used they will convey a very definite meaning or impression, and so serve to identify a particular soil or class of soil.

TEXTURAL CLASSIFICATION

The earliest attempts to classify soils were essentially elaborations of the farmer's conception of light, medium and heavy land ; or sands, loams and clays. These were subsequently given greater precision by being linked with mechanical analyses, in which the actual amounts of sand, silt and clay present in a sample were determined in the laboratory. Henceforth, soils could be classified into light loams, medium loams, heavy loams, clays, etc., upon the basis of their ascertained content of sand, silt and clay. The amounts of the various fractions appropriate to the different textural classes cannot, however, be stated absolutely because of allowances which have to be made for stones, organic matter, calcium carbonate and so forth, all of which may materially affect the position. The basis of the classification is the medium loam which, broadly speaking, contains equal quantities (20–25 per cent) of coarse sand, fine sand, silt and clay. Soils with 25–35 per cent of clay and a consequent diminution of other constituents are classed as heavy loams ; with over 35 per cent of clay as clay soil ; with 10–25 per cent of clay as light loams, and below 10 per cent of clay as sandy soils. When the proportion of silt rises above 50 per cent the soil is usually styled a silt. The following table gives some idea of the textural system of classification.

Table I

SOILS CLASSIFIED IN THE TEXTURAL SYSTEM

Description.	Examples of typical compositions. (per cent.)		
	Sand 2–0·02 mm.	Silt 0·02–0·002 mm.	Clay less than 0·002 mm.
Loamy sand	86	8	6
Sandy loam	70	18	12
Loam	55	27	18
Silt loam	45	40	15
Sandy clay loam . . .	60	10	30
Clay	30	20	50
Silty clay	10	45	45

The predominance of coarse sand, fine sand or silt within the categories already mentioned is indicated adjectivally as " fine sandy " medium loam in the case where a large proportion of the 50 per cent sand fraction is in the form of fine sand, or a " silty " medium loam where the percentage of silt is rather higher than usual. Apart from the difficulties of securing exact standards, this type of classification suffers from certain grave objections when it is used to indicate the distribution of soils by the aid of soil maps. Texture is only one of the many properties of a soil, and as such can have only a limited relevance to the broadest conceptions of soil classification, which should embrace all the important soil properties. If, for instance, the soils of England were grouped into their various textural classes, and these portrayed on maps, it would by no means follow that the soils in any one group would resemble each other in properties apart from texture, such as subsoil and drainage conditions, depth, aspect and elevation.

GEOLOGICAL CLASSIFICATION

Those familiar with the English countryside cannot fail to be impressed by the great influence of geology on soils and on land forms. Some formations such as the Chalk, Old Red Sandstone and Oolitic Limestones are readily recognised by their soils ; others are not so easy to distinguish but, because of the sometimes close connection between soil and geological formation, a geological basis was adopted in many of the earlier soil surveys. For example, Hall and Russell, in their survey of the agriculture of Kent, Surrey and Sussex, distinguished Chalk soils, Wealden soils and Gault soils, amongst others, and within the area studied the method was fairly satisfactory in so far as it enabled the distribution of various classes of soils to be followed by means of a geological map. The system, however, has serious limitations.

A geological map, although often wrongly regarded as such, is not a " parent material " map. The geologist classifies and groups various strata on the basis of their relative ages and not upon the actual nature of the materials ; thus the actual composition of any one formation is by no means constant. For instance, the Forest Marble formation of Dorset, in so far as it is a soil-forming material, is mainly a heavy calcareous clay, whilst the Forest Marble of Gloucestershire is extensively a brashy limestone. Thus it is misleading to speak in the widest sense of Forest Marble soil, however useful such a conception may be in dealing with a small area. Even in the case of " Drifts " the geologist is primarily concerned with their age and origin and only to a lesser degree with the actual nature of the material in question. Equally misleading can be the geological separation of similar parent materials. It is probable, for instance, that little or no difference from a soil-forming aspect exists between the various oolitic limestones—the Cornbrash, the Great Oolite and Inferior Oolite, etc.—or between the Tertiary and Glacial gravels and sands. The use of a geological interpretation of soils, however, tends to foster the reverse impression.

PEDOLOGICAL CLASSIFICATION

Since the beginning of the present century, and mainly through the influence of American and Russian soil workers, efforts have been increasingly directed towards the treatment of the study of soils as a definite branch of natural science rather than as a part of agriculture. For this the name *Pedology* has been adopted.

The Soil Profile. This has led to an important advance in the classification and mapping of soils by the recognition of the *soil profile* as the unit of study. The soil profile is represented by all the distinctive *horizons* or soil strata from the surface down to the parent material, and gives expression to all the processes of soil formation, including physical and chemical weathering, and the vertical movement of soil constituents up or down the profile brought about by soil water. The nature of these processes, and hence the character of the soil profile, is generally governed by climate which also controls the type of natural vegetation, which in its turn influences profile development. The character of the parent material also plays an important part and may under certain conditions be the dominant factor.

Soil Series. Soils with similar profiles, derived from similar material under similar conditions of development, are conveniently grouped together as a *series*. The soil series in Britain is the basic unit of classification and may be subdivided on texture, slope, depth, and other profile features into lower classification categories.

Soil Groups. Avery describes ten major Soil Groups and thirty-nine Sub Groups as occurring in Britain. Since it is outside the scope of this introduction to describe all the divisions and sub-divisions of this system, five of the most important major soil groups, with minor modification, have been selected from Avery's classification. Only the main morphological, chemical and mineralogical features of these soil groups will be described. The groups are :

1. Calcareous Soils
2. Brown Earths
3. Podzolized Soils
4. Gley Soils
5. Peat Soils.

1. **Calcareous Soils.** The occurrence of these soils is closely though not exclusively related to the geological boundaries which demarcate limestone, chalk and other calcareous rocks. Two main sub-groups are recognised : (a) *Rendzinas.* These soils are shallow and of neutral to alkaline reaction throughout. A dark grey brown or black mull humus layer is often the only soil horizon above the parent material, and this contains variable amounts of organic matter and free calcium carbonate. (b) *Brown Calcareous Soils.* Though slightly acid in the surface horizons the soils of this sub-group have calcareous lower horizons. They develop on limestones and highly calcareous sandstones : profiles in Britain are generally brown, freely drained, and of medium to heavy texture.

2. **Brown Earths.** These soils are well, or moderately well, drained. Profiles under natural conditions are leached of soluble salts and carbonates and the tendency is maintained also under cultivation. In the surface horizon, organic and inorganic mineral materials are intimately mixed to form mull humus, and the soils vary from slightly to strongly acid. In some profiles there is evidence of clay movement from upper to lower horizons though, apart from structure differences, there is no marked horizon differentiation. Soils in this group occur in Britain on parent materials from sands and sandstones to clays and shales. Under natural conditions the sandy profiles are usually more acid, and under some conditions podzolize. However, much of the agricultural land of Britain consists of brown earths, and ploughing and cultivation have tended to stabilise profile development.

3. **Podzolized Soils.** Podzolized soils develop in Britain in regions where acid raw humus accumulates under heath or woodland. They are more characteristically found where drainage is free, on light-textured parent materials such as non-calcareous sandstones, sands and gravels. Profiles have a strongly acid layer of raw humus below which is a bleached, mineral zone. Organic acid solutions have

removed iron and aluminium oxide from this bleached horizon, and through precipitation a bright brown horizon enriched in these components is formed below. Some soils display a zone of humus accumulation, which overlies the sesquioxide-rich layer. These horizons are formed under conditions of acid leaching and all are strongly acid. In Britain podzolized soils occur widely, though generally they are found in areas of low to moderate rainfall. In the lowlands extensive cultivation by man has masked, and possibly restricted, the extent of podzolized soils.

4. Gley Soils. Where profile characteristics are the result of water-logging, soils are termed gley soils. They are generally medium to heavy-textured, but sandy soils which occur in basin sites, or above an impermeable sub-soil layer may be termed gley soils. The morphological features of gleys largely result from the effects of waterlogging on iron-compounds in the soil. Waterlogging leads to anaerobic conditions. When this happens the ferric compounds, which impart brown and red colours to the soil, are changed by reduction to the grey or blue-grey ferrous compounds.

Where alternating oxidising and reducing conditions operate due to a fluctuating water table, grey, and rusty mottlings and blotchings are found together in soil horizons. Gley soils are essentially grey in colour, or at least possess a horizon where grey colours predominate. They are often sub-divided into surface-water gleys and ground-water gleys, though this implied relationship to water tables is not fully understood. Surface-water gley soils display a strongly gleyed layer near the surface, resting upon heavier-textured, less-permeable sub-soil horizons which apart from structure faces do not show features of gleying; in contrast, ground-water gley soils are typified by grey and blue-grey colours, and other features indicative of waterlogging and gleying more or less throughout the profile.

5. Peat Soils. Peat soils develop in areas of excessive wetness, and in these conditions plant residues accumulate to give essentially organic soils. Regions of high or moderately high rainfall and low temperature favour peat development as do basin sites where there is a marked excess of precipitation and seepage over evaporation.

Fen peat is formed in basin sites where seepage water is base rich. This neutral to moderately acid peat consists of the humified remains of plants which have inhabited shallow water, intermixed with variable amounts of washed-in mineral matter. With the continued accumulation of humified material, the basin is gradually filled and the free water surface disappears. Plants which demand small amounts of nutrients from the peat below invade the site, and their decaying residues, acid and poor in nutrients, build upwards until a final stage known as *Raised Moss* is reached. Under conditions of high rainfall and low temperatures, acid peats form from a variety of plant associations. Because these peats blanket the uplands, where climatic conditions are favourable, they have been called *Blanket Bog.* They are found principally in western Britain where altitude and rainfall favour this development.

SOIL SURVEY

Despite the fact that the pedological conception of soils has been developed from a purely scientific standpoint largely divorced from agricultural considerations, it quite obviously has important practical applications. This is hardly surprising when one considers the importance to farming of those factors which have been found to determine so largely the evolution of soils, namely climate, parent material, situation and moisture conditions.

When the distribution of the various classes of soil in an area is recorded on a soil map, the convention is adopted of colouring the Podzols various shades of red, the Brown Earths brown, the Gleys blue, Peats purple and Rendzinas yellow. Thus at a glance the map would convey the general locations of acid soils and non-acid soils, wet soils and dry soils, light textured soils and heavy textured soils. A more detailed study, supplemented by reading an explanatory soil memoir of the area, would provide information about less obvious contrasts—those, for instance, which differentiate the various series within a World Group, such as elevation, depth and stoniness, the whole being a useful summary of agriculturally significant data.

A certain amount of survey work has been carried out in this country in recent years, involving portions of Shropshire, Worcestershire, Somerset, Kent, Berkshire, Hants, Dorset and North Wales and other districts in the vicinity of urban areas of the home counties, Birmingham and Leeds ; some of this is available in published form. A considerable amount of survey work, largely directed from Rothamsted Experimental Station, is in progress at the present time.

The following example will indicate a typical recording of soil profile observations. It is slightly abbreviated from a description published by E. Crompton.

CHARNOCK SERIES

Drainage of profile . .	Imperfect.
Parent material . .	Till of Carboniferous material.
Vegetation . . .	*Agrostis*, ryegrass and white clover.
Topography . . .	Altitude 750 ft., 5° slope to West.

Profile :—

0–3 in. . . .	Very dark brownish-grey, tight root mull, organic silt loam, well developed fine crumb to fine granular structure, moist. Clearly defined boundary.
3–12 in. . . .	Greyish-brown loam, very fine blocky to sub-angular blocky structure; numerous roots and root tracks penetrating down from above. Merging boundary.
12–22 in. . . .	Yellowish-brown, with some very pale grey, rather diffused and poorly defined mottling, fine sandy clay loam ; structure is weakly developed but breaks easily to fine crumb ; porous and fissured with some darker old worm tracks penetrating from the horizon above. Merging boundary.
22 in. + . . .	Dull brown, pale grey and ochreous ; old root channels with some darker patches (probably manganiferous), fine sandy clay loam with some fine sandstone fragments tending to be laminated, probably reflecting the bedding of the parent material.

A sample of each horizon from a number of profiles of each series is taken for laboratory analysis ; this enables further data to be obtained as additional criteria for defining the soils. In the laboratory examination attention is directed primarily to those more stable soil characteristics which as a rule can be altered only to an inappreciable extent by the activities of man. These include the percentages of sand, silt and clay, the exchangeable base capacity, and the proportion of silica to iron and aluminium oxides (the silica–sesquioxide ratio) in the clay fraction.

Reference has already been made to man's influence upon soil characteristics, the significance of which is not always appreciated. The mature soils we see are the products of evolutions from earlier forms, due to the varying interactions of parent material, climate, site, etc. ; these soils thus each represent a state of equilibrium between the soil body and its environment. Any act of man, such as liming, drainage or manuring, constitutes a change of environment and hence a shift in equilibrium, which may be sufficiently great to alter the soil from one genetic class to another. The conversion of a Podzol to a Brown Earth by cultivation, liming and manuring is a case in point which, in the agricultural sense, constitutes " soil improvement ". The new point of equilibrium is the result, however, of the artificial introduction of an additional environmental factor, and can only be maintained for so long as the new factor persists. Thus the alteration and improvement of land by good farming can rarely be fully permanent and will last for only so long as the higher standard is maintained. If this is at any time discontinued, the soil will tend to revert to the original state.

THE SOIL AND PLANT NUTRITION

Attention may now be paid to the growing plant to see what its requirements are and to what extent they can be supplied by the soil. Both the atmosphere and the soil play a part in the life processes of plants. To begin with, respiration is continually taking place just as in the case of animals, though in a much less obvious fashion. Some of the tissue of the plant is oxidised with the production of the necessary energy for life and growth. This is accompanied by the liberation of carbon dioxide and water, waste products which are got rid of by the leaves.

Photosynthesis. In the daytime, however, and especially in bright sunlight, another vital phenomenon is apparent. This is the assimilation of carbon dioxide from the atmosphere, where it is always present in small amounts. On the under side of a leaf are found numerous pores or stomata, leading into small internal cavities lined by the walls of active living cells. The air containing carbon dioxide finds its way into these spaces and dissolves in the moisture in the cell walls. The green colouring matter in the cells, called chlorophyll, is able to utilise the energy of the sun's rays which fall upon it, to split up the compound carbon dioxide and build up the carbon so obtained into new substances of the nature of simple sugars. At the same time the oxygen which has been split off is set free and finds its way, via the stomata, into the air once more.

It will be seen then that in the daytime a plant utilises carbon dioxide from the atmosphere to build up its tissues more quickly than it produces that compound by respiration. The sugars produced are then distributed through the growing parts of the plant, and from them are elaborated many other compounds, mostly more complex, which play their part in the building up of its structure. Some of these compounds contain elements other than carbon, hydrogen and oxygen, the constituents of the sugars, and it is these which are obtained from the soil by means of the root system.

Absorption by Roots. The very fine root hairs which the growing plant is continually putting out to explore the soil for nutrient material, push their way amongst the soil particles and lie closely up against their wet colloidal surfaces. The soil solution or moisture in the soil diffuses through the membranous walls of the root hairs and along with it go small amounts of the various chemical substances present in it. The manner in which this happens is not fully understood, but there is no doubt about many of the facts connected with it, such as the enormous amount of water which a plant takes up, passes through its structure and respires from its leaves. There is no doubt, also, that the root system can absorb nutrients from the soil selectively, up to a point.

The substances which are taken in from the soil in this way include nitrogen, phosphorus, potash, silica, iron, magnesium, calcium and others. They pass up into the structure of the plant and, together with the products of carbon assimilation from the leaves, form the materials from which all the various organic compounds comprising the tissues of the plant—proteins, carbohydrates, fats and oils—are produced. So for its growth a plant requires, in the main, oxygen and carbon dioxide from the air, and water, nitrogen, phosphorus, potash and lime from the soil.

Some idea of the quantities in which these substances are required is provided by the two following examples, one afforded by a cereal and the other a root crop. The former, if it yields 22 cwt. of grain and 25 cwt. of straw per acre, removes from the soil 50 lb. of nitrogen, 20 lb. of phosphoric acid, 35 lb. of potash, and 10 lb. of lime, besides other constituents, and during its growth will transpire from its leaves 550 tons of water. A 25-ton crop of mangels removes 85 lb. of nitrogen, 50 lb. of phosphoric acid, 250 lb. of potash and 25 lb. of lime, and will transpire 900 tons of water during its period of growth.

Water Supply. These figures indicate that the biggest demand on the part of a growing crop is for an adequate supply of water, without which no additions of other plant nutrients can exert anything like their full effect. It is an interesting arithmetical study to see what this means when put against the existing rainfall. One inch of rain on an acre gives 100 tons of water, so that for a successful barley crop, the water equivalent to 5½ in. of rain must be actually supplied by the soil and transpired through the plant, which occupies the ground from March to August. In the eastern counties the average rainfall is about 25 in., of which 8 in. will usually fall within the period mentioned. So that it will be readily seen that the physical properties of the soil and the success of the cultivations designed to conserve the moisture in the soil will have a much more potent effect on the barley crop than the various chemical compounds concerned as nutrients, especially when it is remembered that evaporation of water from the surface of the soil is taking place continually, while rainfall is spasmodic.

PLANT NUTRIENTS

It will be noticed from the above examples that nitrogen, phosphoric acid, potash and lime are the mineral substances needed in greatest amount by the growing plant. Other substances are needed also in much smaller quantities and it is usual to classify the essential plant nutrient elements as follows :—(*a*) *Major elements*, or those needed in relatively large amounts : nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. (*b*) *Trace* or *Minor* elements, or those needed in relatively small amounts : iron, manganese, boron, copper, zinc and molybdenum.

A few other elements are taken up by plants with beneficial effects, but do not seem to be essential for growth. Among these are sodium, chlorine, silicon and aluminium.

Mineral Deficiencies. Fortunately most fertile soils in this country are able to supply adequate amounts of all these elements except nitrogen, phosphorus, potassium and calcium, and it is usually necessary to supply these substances only as manures or fertilisers.

It is sometimes necessary to apply other elements as well and those most often required are given below, more or less in order of importance.

Magnesium. Deficiency of this element in crops occurs most frequently on light soils that have been under arable cultivation for some time and have become low in organic matter and have had generous dressings of phosphate and potash. Some soils contain ample natural reserves of magnesium. Symptoms of the deficiency include an intervenal chlorosis but these can be brought on by excessive potash dressings. Root crops tend to show the symptoms on the older leaves as the crop matures ; often there is an unaffected green rim to the leaf. Cereals show the symptoms as a transitory mottling of the leaf when the crop is young ; they may pass off later but some reduction in yield is probable. Blackcurrants and other fruit crops are also susceptible to this deficiency. The remedy is to apply dolomitic limestone when the land comes for liming (see p. 191). If the soil does not need liming more costly forms of magnesium may be considered, such as kieserite or compounds containing sulphate of magnesia. Magnesium deficiency also occurs in stock (hypomagnesaemia). This is a complex problem and not necessarily associated with magnesium deficiency in the soil, but if hypomagnesaemia is feared the first precaution should be to ensure that the soil is well supplied with this element (see p. 710).

Sulphur. Although this element is required by plants in comparatively large amounts, deficiency conditions are very seldom observed since potassium and nitrogen are generally applied as sulphate. Superphosphate also contains notable amounts of sulphate, and crops as a rule receive more than their requirement. Deficiency of sulphur has been reported from other countries, however.

Iron. Cases of iron deficiency in fruit crops arise on calcareous soils or those heavily limed, but are rare among ordinary farm or vegetable crops. The soil invariably contains large amounts of iron, but the strongly alkaline conditions render the element unavailable. The deficiency shows itself as lack of chlorophyll in the growing shoot, and similar symptoms can arise from toxicity caused by contamination of the soil by copper, zinc and other metals.

Manganese. As with iron, all soils contain reserves of this element that are ample for the needs of the crop. If soils containing high amounts of organic matter are heavily limed the manganese becomes unavailable and the crop in severe cases may fail. The deficiency is easily corrected by spraying the crop with a 1 per cent solution of manganous sulphate at 100 gallons per acre which is effective if applied early enough. Cereals are especially subject to this deficiency.

Boron. Boron deficiency occurs naturally in a few soils in Britain, but in the main is induced by alkalinity resulting from supplies of free lime. It is particularly noticeable in dry, light-textured soils. While a very wide range of crops may show symptoms of the trouble, more commonly sugar beet, mangels, swedes and turnips are the most susceptible. In mangels and sugar beet the characteristic symptoms are a rotting of the crown of the root (Heart Rot), while in swedes and turnips the interior tissues are affected and turn brown (Raan or Brown Rot). Treating the soil with a small dressing of borax, about 20 lb. to the acre, will prevent this condition, but compound fertilisers containing boron in the required amounts are available.

Copper. Though copper deficiency is rare it can result in complete failure of cereal crops where it occurs. This is most often on peaty soils that have been acid in the past. The application of copper sulphate (50–60 lb per acre) to the soil provides a spectacular cure. Copper deficiency is also found in pear trees, and the effects are equally dramatic. Only very small amounts of copper are required by the plant and excessive amounts quickly cause toxicity symptoms to appear. Copper toxicity is common in industrial areas and once land has been contaminated in this way it is slow to recover.

Zinc. Although soluble salts of zinc are toxic to plants, sometimes sandy soils have been found where the small amount of zinc required by plants is absent or unavailable. Zinc deficiency has been often reported in America, particularly with orchard trees and maize. Also zinc toxicity, due to zinc minerals in the soil or to zinc-smelting works in the neighbourhood, is of frequent occurrence, and cases are often recorded where excessive amounts of this element have reached the land from applications of refuse materials containing it, such as sewage sludge and the liquid sewage effluent from industrial sources.

Molybdenum. When it is necessary to apply this element it is usual to use sodium molybdate either in solution or at the rate of a few ounces per acre. Cases of severe deficiency are very rare in the United Kingdom though in other countries they appear to be widespread in some restricted areas. The " whiptail " condition in cauliflowers has been proved to be associated with molybdenum deficiency, and molybdenum is necessary in the nodulation of leguminous crops and hence facilitates the fixation of nitrogen. Responses of legumes to molybdate applications are reported abroad, though if the land is well limed this is less likely to occur. It is interesting to note, however, that excess of this element has caused considerable trouble in a few areas known as " teart " pastures, where the herbage has caused excessive scouring in cattle, the grasses apparently containing more of this element than is normal. Soils on the Lower Lias formation in Somerset and elsewhere have caused this trouble, which has been cured by feeding traces of copper compounds either direct to the stock or through the pastures.

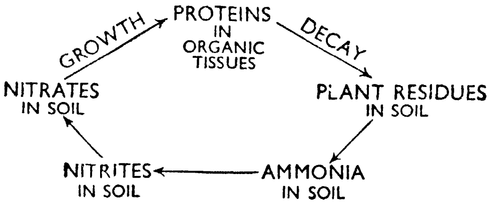
AVAILABILITY OF NUTRIENTS

The utility of fertilisers is, nowadays, demonstrated beyond doubt by the huge dimensions of the fertiliser trade, and most people are personally acquainted with instances of marked responses by crops to their application. Yet when the increases in crop produced, the amount of added fertiliser, the amount of the particular constituent removed by the crop, and the amount of it present in the soil are all considered together, no very obvious connection is apparent.

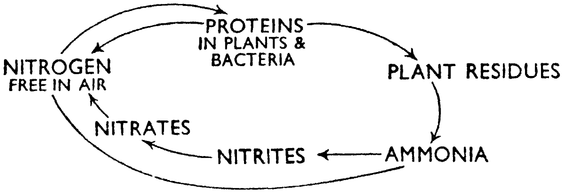
The average arable soil contains about 0·2 per cent. of nitrogen, which, in an acre of soil 9 in. deep, represents 5,000 lb., an amount enough to supply this constituent for as many bushels of grain. But the roots of wheat, for instance, in their search for plant food, go much deeper, so that they come into contact with an even greater amount of nitrogen, probably not exaggerated if put at 10,000 lb. per acre. In spite of this, it is found that the average yield of wheat on the classic unmanured plot at Rothamsted, containing an amount of nitrogen of this same order, is steady at about 12 bushels per acre. On a neighbouring plot, receiving annually 40 lb. of nitrogen in the form of concentrated fertiliser, an equally steady average yield of 22 bushels per acre is maintained. This would suggest that the total amount of nitrogen has little direct bearing on the size of crop grown, but that there is probably a factor of great importance in the form in which the plant can assimilate it.

If a similar rough calculation is made of the amount of nitrogen present in the soil in forms similar to nitrate of soda and sulphate of ammonia, the figures obtained take on a more ordered aspect. There are found in the soil at different periods of the season varying amounts of two comparatively simple compounds of nitrogen, namely nitrates and ammonia, of the order of 0·001 per cent of nitrogen as nitrates and 0·0001 per cent of nitrogen as ammonia. These represent, per acre, a total of 25 lb. at any moment. This figure is substantially of the same order as the amount of nitrogen in the fertiliser dressings referred to above, so that there is strong support for the view that the amount of nitrogen present in the soil in an assimilable form, e.g. as nitrate, has a direct bearing on the crop yield. It has already been indicated that the bulk of the nitrogen present in the soil is in the form of complex protein-like compounds in the humus or organic matter, and that these are constantly being broken down into simpler compounds by the action of specific bacteria, until they result in the production of ammonia which, in its turn, is converted into nitrate. The organic nitrogenous compounds are mostly insoluble and certainly not able to be absorbed into the root system, while ammonia and nitrate are comparatively simple in composition, readily soluble in water, and easily assimilated by root hairs.

The Nitrogen Cycle. This sequence of changes forms part of what is known as " the nitrogen cycle ", or the way in which the element nitrogen is continually in circulation in nature. In its simplest form it can be set out as follows to illustrate the continuous growth and decay of plants.



But the activities of bacteria and the processes of decay are not merely the mechanism of this simple cycle ; they have trends of their own leading in other directions, as indicated in the following version :—



Some of the nitrogen of the proteins is set free and added to the store already existing in the atmosphere, while some of that in the nitrates produced in the soil suffers a similar fate. On the other hand, several different bacteria can feed on the free nitrogen of the air and elaborate it into proteins in their own bodies.

Sufficient has been said, perhaps, to indicate the respective influences of proteins and nitrates, to mention the two most important stages of the cycle, upon the fertility of the soil and the growth of plants. The proteins constitute the reserve in the soil, the material from which a constant supply of easily assimilable nitrates is produced. The rate of this production depends on the temperature, moisture and aeration of the soil. It is at a low level during the winter months, but as soon as the soil warms up in spring it rises rapidly, with the result that the amount of nitrate found in fallow land constantly increases until September, when production falls off and drainage commences once more, gradually reducing the amount to its winter minimum. In the case of land under a crop, the nitrate is continuously absorbed, with the result that the amounts found reach their maximum in June, then fall off steadily until August, rise again to an autumn maximum in October, and then again decline to the winter level.

It will be understood from this brief outline that easily soluble nitrogenous compounds used as top dressings in the early spring, before nitrification is really active, are in a position to exert a very potent influence on the growth of a crop in its early stages. It also follows that the effect of such fertilisers is exerted within a short time of their application and that they are unlikely to have a permanent effect in raising the fertility of soil. But there are many materials of undoubted value as manures which in themselves are more of the nature of proteins. All the organic refuses (see p. 174) come into this category, so that their use produces rather different effects. They do, in fact, increase the reserve of nitrogen in the soil at the same time as they add some of it in a condition in which it easily progresses through the cycle, i.e. is soon converted into nitrates. The users of this class of fertiliser generally make it a practice to add supplies regularly to the soil, thus steadily enhancing its fertility and ensuring that when the nitrification processes are active, the amounts of nitrate produced may be correspondingly increased all through the season. This kind of treatment is much more essential for some crops than a liberal supply of available nitrogen given early in the growing season, as in the case of quick-acting top dressings.

AVAILABLE PLANT FOOD

The consideration of nitrogen as a plant nutrient and the relations between the store present in the soil and the amount actually absorbed by the plant has served to illustrate what is meant by the term " available plant food ". This is an expression frequently employed in technical phraseology with regard to the nutrition of plants, to call attention to the fact that it is not so much the total amount of any one constituent which matters as the extent to which that constituent is in a form assimilable by the plant roots, or, in other words, how much of it is available. In the case of nitrogen there are a number of established facts, as indicated above, which enable a fairly clear idea of the position in the soil to be obtained.

In the case of those other important nutrients, the mineral constituents, especially phosphates, potash and lime, our knowledge is not quite so satisfactory. Looking at them on the same simple quantitative basis, it is found that a common figure for the amount of phosphoric acid in a soil is 0·1 per cent, which, by calculations similar to those employed in the case of nitrogen, represents over 5,000 lb. within root range, and yet by the addition of 2 or 3 cwt. of superphosphate, containing about 40 lb., remarkable effects on the crop are frequently obtained.

In the case of potash, a much greater range of total content in the soil is experienced, from 0·1 per cent or less in light, sandy soils to over 1 per cent in heavy clays, representing from 5,000 to 50,000 lb. per acre within root range; but again, when the soil responds to applications of this constituent, it does so to dressings containing amounts of the order of 40 lb. per acre.

The phosphoric acid in the soil is present partly as mineral matter, such as calcium phosphate, and partly as a constituent of the organic matter. The potash is there as a constituent of the original minerals or of their partly weathered residues. In the soils of the south-eastern half of England it occurs chiefly in the smaller particles, particularly in the clay fraction, so that the total amount increases with the heaviness of the soil. That all these compounds, whether phosphate or potash, are practically insoluble in water is evidenced by the very small amounts which are found in drainage water or in the soil solution.

METHODS OF ASSESSING AVAILABILITY

At the same time there is evidence that in some soils the phosphate is more " available " to the plants than in others. It is possible to find instances of soils containing the higher amounts of total phosphate which respond to added phosphatic fertilisers, while others with a lower total content show no response. Phenomena of this kind led to the view that there are differences in the state or constitution of the phosphates in soils, making them more or less easily assimilable by plant roots. It was also suggested that the root systems excreted acid juices which could dissolve the mineral nutrients, phosphate and potash, and so render them useful to the plant.

Dyer's Citric Acid Method. After a period of experiment, Dyer came to the conclusion that this action of the roots could be very closely imitated in a laboratory by shaking up the soil with a 1 per cent solution of citric acid under certain standard conditions. By means of this test he was able to differentiate between soils with respect to the amounts of " available phosphate " and " available potash " which they contained. His results agreed fairly well with the actual response of the soils in the field to added fertilisers, and to this day his method is widely employed by advisory chemists to assess the need of soils for these particular constituents. Such practitioners, by dint of accumulated local experience and data from the soils with which they are familiar, are able to set up in their own localities certain standard limits about which they can dogmatise with a fair degree of accuracy. For instance, in some areas available phosphoric acid below 0·01 per cent is considered to be deficient and over 0·02 per cent to be adequate, and, as a rule, the response of the soils to added phosphate will be in accordance with these tenets. Similarly 0·007 and 0·014 per cent might be the corresponding limits for potash.

It is obvious that such standards cannot be regarded as hard and fast, but, due consideration being given to other known facts, such as the history of the field and the behaviour of the crops on it, this form of analysis is a valuable aid to a correct diagnosis.

A useful modification of the method consists in studying the ratio of the "available" to the "total" amount of either constituent instead of the absolute percentage. The following examples are from different fields on one farm :—

Per cent.	1	2	3	4	5	6
Total phosphoric acid . . .	0·123	0·092	0·083	0·119	0·116	0·243
Available phosphoric acid . .	0·013	0·011	0·025	0·033	0·031	0·016
Available as % of total . . .	11	13	30	28	27	7
Total potash	0·248	0·332	0·147	0·115	0·164	0·492
Available potash	0·016	0·012	0·023	0·007	0·005	0·017
Available as % of total . . .	7	4	15	6	3	3

Numbers 1, 2 and 6, by this criterion, seemed to be short of available phosphate ; in practice they were the fields where phosphatic fertilisers produced the bigger response. There is not such a marked contrast in the case of the potash. On the ratio of available to total potash, they all look poor except number 3, while in practice numbers 4 and 5 gave the best results for the use of potash.

It is difficult to define or explain this "availability" of plant nutrients, although different workers have attacked the problem from many angles. It is 200 years since that pioneer Jethro Tull expounded his views on the subject, and they bear a very close resemblance to some of those expressed by eminent soil scientists of the present day. He realised the tremendous importance of tilth in making a soil productive, and the connection between it and the internal surface area of the soil. He regarded this as the "pasture" area of the soil so far as plant roots were concerned, and devoted all his energies to the improvement of tillage implements in order to keep this area at its maximum. In his day little was known of the chemistry of the soil or of plant nutrition. He was convinced that an important part, if not all, of the necessary nutrients resided on the surface of the soil particles, and so argued that the more of this surface there was made accessible to the searching roots the more nutriment the plant would obtain. Enough has already been said in the present account concerning the soil solution and the action of plant roots on the colloidal surface of the particles to show that his line of reasoning had very much the same trend as that of subsequent workers.

It must be remembered that the need for, or the effect of, such constituents as phosphoric acid or potash in soils is, to a great extent, determined by a number of circumstances which render it difficult to state anything in the nature of standard requirements. For instance, the amount of phosphoric acid required in the case of a heavy soil may be greater because its function in developing a vigorous root system is more important for the crop than it otherwise need be, on account of the greater resistance offered by more sticky soil to the movement of growing root hairs. Or, in conditions of insufficient water supply, a correspondingly larger root system may be necessary to the plant in order that it may more thoroughly search the soil to obtain its due supply. Further, the bases with which the phosphoric acid is associated may influence the ease with which the plant can assimilate what it needs; the value of the phosphates of iron and aluminium, as compared with those of calcium, is not necessarily the same. In the case of potash, it has been clearly demonstrated that the need for it is very definitely connected with the amount of rainfall during any season, and so with the moisture content of the soil.

Other Extractants. Dyer's method is quoted as an example of an available nutrient determination, but many other similar methods have been tried and as these are more convenient in a laboratory where many routine soil analyses are carried out Dyer's method is not now widely used. Extractants can be vigorous or gentle according to whether they extract a high or low percentage of the total plant nutrient, and as the various crops differ in their ability to absorb the nutrient in question, no one extractant is likely to have universal application. Many workers have observed that when a soil sample has reached equilibrium with an extractant there still remains a further smaller amount of nutrient in the soil that could be extracted by means of a second extraction. Thus the use of a large amount of solvent for a given amount of soil extracts a proportionately larger fraction of available nutrient. The following solutions are among those used in available nutrient determinations:

N/2 acetic acid (solvent : soil = 20 : 1)
N/2 acetic acid + 10% sodium acetate : Morgan's solution (solvent : soil = 5 : 1)
N/5 sodium bicarbonate : Olsen's solution (Solvent : soil = 20 : 1)
3N sodium nitrate (solvent : soil = 2 : 1)

Other methods of assessing the availability of the mineral plant foods in a given soil have been tried out by investigators in recent years, especially on the Continent, by a more direct appeal to the plant, instead of by soil analysis. On the grounds that a single nutrient factor, such as phosphoric acid, exerts a specific effect on the crop, as evidenced by the yield, attempts have been made by studying the yields obtained by varying additions of a single manurial constituent, to calculate the amount of this originally present in the soil. This method has been severely criticised because of the difficulty of isolating the effect of a single factor where so many are obviously concerned. This drawback, coupled with the slow and laborious nature of the investigation, precludes its general adoption.

Neubauer's Method. There are, however, investigational methods which are more rapid and more easily carried out which have attained a certain measure of success. That of Neubauer is an example. This worker relies on the ability of seedlings, given favourable circumstances, to extract all the available plant food in a given sample of a soil within a comparatively short time. His procedure is somewhat on the following lines. He mixes a small quantity of his soil sample with about three times its weight of pure sand, sets it up in saucers, plants in each 100 seeds of rye or barley, and keeps the whole at carefully regulated conditions of temperature and water supply for seventeen days. At the end of this period the seedlings are lifted, carefully washed free of soil, dried, and analysed for their content of phosphate, potash, etc. The figures obtained are then used to determine the sufficiency or lack of any individual constituent in the particular soil under experiment. This line of attack has been much used, since its discovery, by the fertiliser interests in Germany, in connection with field investigations and for routine advisory purposes.

Larsen's Method. Recently the advent of radioactive tracers has given another type of method to the soil chemist. By adding a certain amount of radioactive phosphorus (P_{32}) to the soil and measuring the activity of the plant grown on it and that of the soil a direct measure of the ability of the soil to provide phosphate can be obtained. Fried and Dean have developed a similar method in America. It is harder to apply the method to potassium and other elements because of the absence of isotopes with half lives of convenient duration.

SOIL REACTION AND LIME STATUS

There still remains to be considered one constituent of the soil which ranks as a very important food nutrient but which is the more indispensable because of its effect on the condition and fertility of the soil. This is lime, or the calcium base, which is absorbed by plants along with their other food materials, but which also has a dual effect on the soil in improving its structure and in keeping its reaction sweet and suitable as an environment for most of our crops and for the beneficial micro-organisms which so greatly influence fertility.

Soil Reaction. All materials in the presence of water can be either neutral, alkaline or acid, and the degree of acidity or alkalinity is expressed in terms of a scale, known as the *p*H scale, on which the neutral point is numbered 7. Numbers above 7 indicate alkalinity, and below 7 acidity, the alkalinity and acidity being greater the further the number deviates from 7. Alkaline conditions are due to the presence of bases such as lime, soda or potash, while acid conditions are due to acids, an example of which is citric acid, present in fruits such as lemons. When the soil is well supplied with bases, particularly lime, the soil will have a neutral or even slightly alkaline reaction, with *p*H values from about 7·0 up to about 8·0. When such bases are lacking, acid conditions set in, and the soil will have *p*H values less than 7, which in extreme cases may fall as low as *p*H 4·0. As plants appear to be fairly responsive to the reaction of the medium in which they grow, being able to tolerate only slightly alkaline or slightly acid conditions, the farmer must maintain the soil at the right state of reaction.

Most soils in this country have a reaction on the acid side, i.e. they have *p*H values less than 7·0, but exceptions may be found in soils on the chalk and limestone formations or in soils which have been limed recently. Plants can be divided roughly into groups according to their natural ability to grow under (1) very acid, (2) moderately acid, (3) slightly acid or (4) alkaline conditions. In the first group are found wild plants such as heather, bracken, bilberry, rhododendron, spurrey (mountain flax, sandweed, dither, yarr, etc.), sheep's sorrel or sour dock, and such agricultural crops as potatoes, rye and oats. In the second group we find other wild plants and agricultural crops such as wheat, swedes, turnips, kale, ryegrass and wild white clover. In the third group are found mangels, sugar beet, barley, carrots, red clover, beans and peas, while the lime-loving plants in the fourth group are the wild plants usually found on chalk lands, such as scabious and burnet and the agricultural plants lucerne and sainfoin.

The above division is not exact, since most plants tolerate a range of reaction sufficiently wide to bring them into more than one group, but the differences are sufficiently marked to enable many of these plants to be used as indicators of the general soil reaction. Thus, on arable land, the presence of spurrey or sour dock may indicate a very acid condition if these plants grow in large numbers to the exclusion of the more sensitive agricultural plants such as sugar beet, barley or red clover. The failure of the sugar beet crop can be instanced as a good example of what happens under too acid a soil condition. The plant grows normally until the hoeing stage, after which growth practically ceases and the plant assumes a stunted appearance, becoming pale in the leaf, while root development is checked and the plant may die. With very acid conditions the plant may die immediately after germination. The failure of the crop allows weeds to grow without competition, and spurrey and sour dock tend to smother any weakly plants which have survived. A very usual symptom of soil acidity is patchiness of the crop, rather than complete failure, since the soil is never uniformly acid all over the area. With barley, excessive acidity results in a rapid diminution of the crop and the consequent patchiness is always very evident. Root growth is stopped and a stunted, dark-coloured root system results. Red clover is the most sensitive of all the common agricultural crops to acidity and usually fails to reach the seedling stage. Wild white clover and alsike clover can withstand much greater acidity than the other clovers.

Crop Tolerances. Different crops require different *p*H values for optimum growth and can tolerate different degrees of acidity

Group.	Crop.	Optimum pH.	Dangerously low *p*H.
I	Lucerne Sainfoin	7·0	5·8
II	Sugar Beet Mangels Barley Red Clover	6·5	5·4
III	Wheat Brassicas Wild White Clover	6·0	5·0
IV	Oats Potatoes Rye Ryegrass	5·8	4·5

before failure of the crop is likely. Soils differ in their nature in this respect : peat soils can support growth of crop plants at a lower *p*H than mineral soils and on the latter ample treatment with farmyard manure can go a long way to mitigate the effects of acidity. Highly organic soils, however, are more likely to give rise to trouble at high *p*H (neutral or alkaline). The common crops can be divided into groups as on p. 31. The *p*H figures would be average for a mineral soil of average humus content. They are intended only as a rough guide.

The Nature and Effect of Soil Reaction. It has previously been indicated that the reaction (*p*H) of a soil is largely determined by the condition of its clay and humus. These may be, in extreme cases, hydrogen saturated and behave as insoluble acidic compounds ; or calcium saturated and behave as insoluble alkaline compounds. Acids such as sulphuric, nitric and carbonic (mineral acids) are constantly being formed in the soil water due to biological activity, and brought into contact with the colloids ; if the latter are themselves acidic then the soil solution will maintain a similar reaction ; but if the clay and humus are calcium saturated some of this calcium will be liberated to neutralise the dissolved acids, and so the soil solution will become non-acidic. The calcium lost from the colloids is replaced either by the hydrogen from the original mineral acids, in which case the colloids become progressively acidic, or by more calcium if the soil has reserves of calcium carbonate, or is limed.

Although there is often a close connection between crop failure and low *p*H, as shown in the previous table, the assumption cannot be made that it is the acids themselves, or the exchangeable hydrogen, which inhibit plant growth. It has long been known that plants grown experimentally in sand or water cultures can succeed at *p*H ranges well below the failure levels of field conditions, suggesting that other factors are involved in addition to that of direct acidity. Some of these factors are considered elsewhere and need only be indicated at present. They include the indirect effects of acidity on the physical condition of the soil, on the activity of soil micro-organisms, on the prevalence of plant diseases and on the competitive powers of weeds.

Two other indirect effects of soil reaction merit further consideration—the effects upon the availability of essential plant nutrients, and upon the solubility of toxic substances. Essential elements such as iron, manganese, copper, zinc and boron appear to become less soluble when the *p*H rises above the neutral point (*p*H 7). This lowering in availability sometimes explains the unfavourable results occasionally reported as a result of heavy liming. At the other extreme, increasing acidity enhances the solubility and hence the availability of certain elements, notably manganese and aluminium, to the extent that they may become harmful to plant growth. Recent investigations have shown that for certain crops the characteristic " acidity " symptoms are probably due to manganese toxicity under conditions of low calcium intake. In other words, a given soil, in relation to certain crops, might be manganese " deficient " at high *p*H, manganese toxic at low *p*H, and of a satisfactory soluble manganese status in the intermediate range of perhaps *p*H 5·5 to *p*H 7·0.

Causes of Soil Acidity. We must now mention the reasons why soils become increasingly acid year by year unless adequate dressings of lime are applied when they are needed. The chief cause of soil acidity is the fact that the easily exchangeable bases held by the soil colloids (clay and humus) are removed in a soluble form by rainwater as it percolates through the soil. The rainwater is slightly acid due to carbonic acid gas (CO_2) in solution and various " humic " acids formed by the decay of humus, and these weak acids remove the absorbed or exchangeable bases, particularly lime, so that they are washed out or leached from the soil and lost in the drainage water. Light, sandy soils have the lowest capacity for holding exchangeable lime and, being freely drained, lose this lime rapidly by leaching. It is therefore on such soils that soil acidity most commonly occurs, but from their nature, they are the most easily corrected, only small amounts of lime being needed to restore fertility. On the other hand, heavy clay soils, or soils rich in humus, hold much larger quantities of exchangeable lime so that soil acidity develops much more slowly. But even these soils may in time reach such a state of acidity that crops begin to fail or grass land begins to deteriorate and become matted ; in such conditions small dressings of lime are of little use. Large or repeated applications of lime are often needed, and on grass land it may be necessary to plough out and re-seed so that the lime may be mixed effectively with the soil. The rate at which lime is removed from the soil in the drainage water varies, of course, from soil to soil and according to rainfall, but it may be taken to be from 1 to 4 cwt. (as CaO) per acre per annum.

Besides these losses from the soil by natural drainage, the crops themselves extract amounts of lime each year, since it is an essential plant constituent, and if the crop is not returned to the soil again by ploughing in, a certain amount of lime is removed from it. This loss is small in comparison with that caused by the removal of lime in water draining through the soil.

Chemical Tests for Soil Acidity. The presence of appreciable amounts of *free* lime in the soil may be shown by adding a little dilute hydrochloric acid to some of the soil, when a fizzing will result, due to the action of the acid on the calcium carbonate.

Soil Indicator. But soils may be fertile and not in need of lime, even if they are devoid of free lime ; numerous field trials have shown that slightly acid soils (*p*H about 6·0) are still able to grow good crops. Hence a sensitive test has been devised to measure the *p*H value of the soil in the field by using the so-called " soil indicator ", which is a solution of various synthetic dyes, the colours of which change according to the degree of acidity of the soil when mixed with the indicator. The value obtained is only an approximate one, but it has proved useful in field work to discriminate between soils which are very acid and those which do not need immediate liming. Accurate *p*H determination is carried out in the laboratory by electrometrical methods.

Lime Requirement. If a soil has been shown by the above tests to be too acid to grow crops satisfactorily, it is then necessary to ascertain the amount of lime which should be applied. This is done by determining the " lime requirement " of the soil by another chemical method, which again needs the apparatus of a laboratory. The lime requirement figure is stated in terms of the amount of lime (expressed as carbonate of lime, $CaCO_3$) needed in cwt. per acre. It is usually only necessary to determine the lime requirement of those soils which have a *p*H value less than about 6·5 as it has been found in practice that it is only such soils which need liming. The application of lime to soils having *p*H values greater than 6·5 would be wasteful, and on some soils might be definitely harmful as it might induce manganese or boron deficiency in the succeeding crops. In any case it must be remembered that some experience is needed in interpreting the results of chemical analyses, because such factors as soil texture and the nature of the crop to be grown must be considered before deciding upon the precise amount of lime which should be applied.

THE LIMING OF LAND

Details of the various forms of lime which can be used to correct acidity will be found in Chapter VII. The time and method of application of these products to the soil will now be considered.

On arable land the lime should be applied after ploughing, as a more even distribution can be made and the material can be well worked into the soil without burying it too deeply. Both the soil and the lime should be as dry as possible. The lime should be spread on the furrow and well harrowed or cultivated into the soil but, for small dressings of up to 1 ton per acre, it is best applied through the drill as finely ground material. If the soil has been found to be badly in need of lime, the first opportunity should be taken to apply the lime, whatever the next crop ; but if the dressing is intended only to maintain a reserve of lime and to keep the land in condition, the most suitable time in the rotation is during the first preparation of the land for a root crop other than potatoes. The potato crop is unsuitable because the tubers are likely to be affected with Common Scab after recent liming.

On grass land the lime is best applied in autumn or winter, particularly if burnt lime is used, as large dressings of this form of lime are liable to check growth if added in the spring. The herbage should be dry when the dressing is put on and the turf should then be heavily worked with pitch-pole or other harrows to ensure that the lime is well mixed into the surface soil. Other forms of lime, such as ground limestone or chalk, may be used much more freely on grass land, and at any time of year, since their action is less severe. Grass land which has been allowed to become very acid gradually deteriorates, and the dead material decays so slowly that it tends to accumulate and form a fibrous " mat " on the surface. In these circumstances it is best to plough out the old turf and apply the lime to the exposed soil. The lime is worked thoroughly into the soil, after which the land may be re-sown at once (with application of appropriate fertilisers) or cropped for a few years with arable crops before sowing down to grass again.

The length of time during which the effect of an application of lime will last depends on several factors, such as soil type, rainfall, type of crops and manurial treatment, all of which affect the rate of removal of lime from the soil. As a rough guide under average conditions it is usually assumed that a dressing of 1 ton of carbonate of lime (or 10 cwt. of burnt lime) will last from four to six years. A condition which needs to be watched with great care occurs in some soils overlying limestone or chalk. Leaching of the lime from the surface soil may have taken place to such an extent that the residual soil is acid, although free lime is present beneath the subsoil; immediate liming of the land may be necessary.

Other Beneficial Effects of Liming. Besides correcting soil acidity, liming confers other beneficial effects on the soil. Thus heavy soils containing a high proportion of clay are improved in structure by liming. Under the influence of lime the fine clay particles tend to clump together to form larger aggregates, thus imparting easier working properties to the soil. The whole of the bacterial activities taking place in the soil, such as the production of nitrates from nitrogenous organic matter and the fixation of atmospheric nitrogen by free-living organisms such as Rhizobia, Azotobacter and Clostridium, occur more rapidly in soils supplied with lime. The accumulation of undecomposed mat on grass land, as mentioned above, is a direct result of the inability of the micro-organisms to function correctly under acid conditions. An improvement in herbage quality as well as in quantity is obtained by liming grass, more lime being taken up by the herbage and built up into organic calcium compounds. This improves the feeding value of both grass and hay. Finally, the relation of liming to plant diseases should be mentioned. Lime has long been used to combat attacks by Club Root (Finger-and-Toe) on cruciferous plants. The appearance of this disease has usually been taken to indicate soil acidity, but this is not always the case, as the symptoms have been found on neutral soils. There is evidence, however, that dressings of lime assist in preventing the disease, an increase in soil *p*H to about 7·0 having a beneficial effect (see p. 358).

Chapter II

FIELD DRAINAGE

THE practice of field drainage is almost as old as that of agriculture itself, a recognition of the fact that while a proper supply of moisture is essential to the successful growth of crops, it not infrequently happens that in the soil there is present an excess of water with decidedly harmful effects. The farmer's problem is to preserve the best possible balance between the two, to ensure an equable and constant supply of water and to avoid the presence of an excess. Left to herself, nature produces a balance between soil conditions and plant growth which is a reasonable optimum for the seasonal cycle of the weather. In considering the soils of this country attention was drawn to the great influence of the drainage factor on their general characteristics. Much of our land in its natural condition was ill-drained, and while nature clothed it with a vegetation suited to the circumstances, its conversion to farming was not successful until drainage measures were taken to remove the excess water and prevent the recurrence of water-logging.

The importance of field drainage in this country is evident from the amount of attention which it has received during and since the war of 1939-45 and, indeed, at all times other than those of agricultural depression. Apart from major undertakings on arterial drainage channels and reclamation schemes, the amount of work done since 1939 includes the renovation of the field ditches of 6,000,000 acres of land, the tile draining of 500,000 acres and the mole draining of 600,000 acres. During the prosperous times of agriculture between the years 1846 and 1872, intensive tile draining was carried out on some 1,200,000 acres. Indeed, at some time or other, all the farm land of the country which for reasons of soil or site could benefit from artificial drainage has been so improved at least once in its history.

Disadvantages of Wet Land. Wet land is late land and one of the chief objects of field drainage is to remove this disability. Fields which habitually lie wet for a substantial part of winter are slow to dry and warm up in the spring, implements cannot be got on to them soon enough, cultivations are late and their results are less satisfactory. The deterrent effect of high ground water level on root development and the harm which can follow a rise during the growing season are well known. In the development of crops the early stages of growth are of great, even vital, importance and on this growth soil temperature has a potent influence. Its response to increasing sunshine in the spring is greatly influenced by drainage conditions. The higher temperatures attributable to drainage were realised by the famous drainage engineers of a hundred years ago. Josiah Parkes recorded a gain in temperature of 13° F. at a depth of 7 in., in the middle of June, in drained bog land. Bailey Denton found a benefit of 2° F. from March to May, at a depth of 18 in.

in drained clay land. Such records have been confirmed and supplemented in more recent years by American observers.

Soils which are perennially water-logged are structureless, their subsoils in particular are tight-packed, and the water in them is stagnant. Soils which are seasonally water-logged, such as clay land and heavy land in general, have the same disabilities except that the summer, especially in droughty years, causes substantial drying-out from the surface downwards. The effect of this becomes evident in the shrinkage, cracking and structuring of the soil mass, the aggregation of the soil particles into larger units, and the appearance in the soil of a system of larger interspaces than were there before. This is the essence of permeability. Clay land drains better after a dry year than after a wet one. Careful study has led to the opinion that a good drain line leads to a steady improvement in the physical condition of the soil about it. In drainage one thing leads to another. The removal of stagnant surplus water allows root systems to develop in greater depth. The simultaneous improvement in soil structure and permeability also helps, the pore space is increased and aeration benefits accordingly. At the same time, in spite of the removal of much water, the amount of moisture available to the growing plant is substantially increased because the roots can derive their supply from a much greater depth of soil, in much more healthy conditions.

The Movement of Water in Soil. In general, the amount of moisture in soil depends on how much it receives as rain and how much it loses by evaporation and transpiration. The soil acts continuously as an absorbent and storage reservoir, so that losses due to the latter factors are sooner or later made good by the former. In this country the rainfall is more or less evenly spread over the year but the loss of moisture from the soil is distinctly seasonal. At the spring equinox the increasing power of the sun and the lengthening days combine to cause evaporation at a rate which can exceed that at which the rain is received. Based on monthly averages, this is particularly true of the predominantly arable south-eastern half of the country, and is generally applicable to all but the mountainous regions. In the spring and early summer, accordingly, we find that drain flows slacken and in heavy land cease altogether before midsummer. Evaporation and transpiration together deplete the soil of its reserve of moisture, working from the surface downwards.

The measure of this reserve is impressive : Five feet of clay soil, for instance, holds moisture equivalent to 30–35 in. of rain, even when drained, though some of this is too tightly held by the soil to be available to the plant roots. An average crop uses 6–8 in. of rain during its growing period. As a result, the normal autumn condition is one of a deficiency of moisture in the soil, varying in amount according to the summer season. Normally, it will be of the order of 3–4 in., but after a droughty summer may be as much as 8 in. Such rains as come in summer, of course, interrupt this trend, but as a rule do not obliterate it entirely. At the autumn equinox, when rainfall once more begins to exceed evaporation, there is still as a rule storage room for much of the autumn and early winter rains before an excess appears in the soil and percolation and drainage ensue. From time to time we have a run of years with abnormally low rainfall—sequences of droughty summers with dry winters between them ; the soil may even fail to become remoistened to capacity and so the drains do not run and the springs fail to rise.

If more rain falls than can be retained by the soil the surplus moves downwards under the influence of gravity, provided that there is no obstacle to its percolation. The characteristic of the soil which determines the extent to which this can take place is called " permeability " and it depends on the texture and structure of the soil mass and of the underlying geological material. If this is coarse and open, as in the case of soils lying on deposits of gravel or sand, the water can move downwards through the comparatively large interspaces with fair ease. If, on the other hand, the soil mass consists chiefly of the finest mineral particles, as in the case of clay, water cannot percolate through it easily, if at all. Such material can only attain a measure of permeability as a result of the channels made by earthworms or by decaying roots, or of the development in it of what is known as " structure ", which arises out of the process of weathering and its effect on the clay particles. These particles are of a colloidal nature and display a marked degree of shrinkage on drying and of swelling on re-moistening. The broad effects in field conditions are the well-known fissuring of the ground in summer, and the splitting of the clay soil into structural units with a network of interspace amongst them which persists somewhat even after remoistening and swelling. But this only affects the top foot or so of the soil and its benefit is temporary. Such land is essentially impermeable and, in the absence of a drainage system, wet periods will be accompanied by surface water-logging.

But even in the case of soils of the most open nature we find instances of bad and persistent water-logging, which can arise from two causes. If an otherwise permeable soil lies on an impermeable geological formation, it will be liable to water-logging if the depth to the obstructing material is only a few feet, because in wet times the surplus water percolating downwards piles up on the impermeable floor as a rising ground water level, which, if it comes within about 3 ft. of the surface, has important effects on the soil. The other cause of trouble of this kind is that while percolation is mainly a vertical downward movement, the resulting body of ground water moves in a different fashion, influenced by the shape of the impermeable floor on which it rests and the differences in hydrostatic pressure which arise. So we have to deal with the possibility of trouble due to foreign water, i.e. water which fell as rain or otherwise entered the soil at a distance and then moved underground to come to the surface where it is ultimately found, the result of certain combinations of topographical and geological features. It must be remembered that it is differences in permeability that matter. A layer of moderate permeability underlying one of a very open nature will impede percolation in times of heavy rain. This impedance, acting in conjunction with sloping ground, causes lateral movement of water and accounts for many localised wet spots. The vital importance of the nature and properties of soil in the field is often lost sight of in this connection. We discuss and think of soil as a material, something which is manipulated in the business of farming, and unconsciously tend to regard it as being homogeneous. This is not so. All soil characteristics are liable to vary with depth, and natural variations of this sort, especially permeability, are accentuated by tillages. Thus it comes about that soils which in nature drain well enough are found under farming conditions to acquire a propensity to seasonal drainage troubles. Plough pan is not an uncommon cause of defective soil drainage, and in conjunction with sloping ground aggravates it locally.

Heavy soils and peaty soils have a much greater absorptive capacity for moisture than the light and sandy soils, and so it is common experience that, if markedly different soils are found within the same farm, the light land drains become active earlier than those of the heavy land. Further, the fashion of events is different in the two cases. The drains of open soils start gently, and flow continuously, with gradually increasing rates as the winter advances. The heavy land drains, by contrast, suddenly gush forth after a particular shower, flow at a great rate for a short time and then fall off to a trickle until the next rain.

FIELD DRAINAGE PROBLEMS

The farming community has been wrestling with the problem of surplus soil water from its earliest days, so what more useful background could one have to the study of present-day difficulties than the history of drainage efforts in this country? About the large-scale drainage system of the country no more need be said than that it has consisted in the main of the protection of certain areas from the influx of foreign water, the improvement of the natural river systems and their supplementation with artificial channels to get rid of the surplus water originating in those areas.

On the field scale, one of the oldest practices, dating from the times when the land was farmed in small parcels and the drainage efforts of one individual were liable to be nullified by the lack of co-operation or even the active opposition of his neighbours, was to work the land on the ridge and furrow system, which did at least ensure a modicum of land moderately well-drained, even in the worst seasons. This method lent itself particularly well to the clay-land areas, where it exploited the natural tendency of the impermeable clay to get rid of its surplus water by surface run-off.

The establishment of underground drainage channels, of course, was an obvious early development, but the materials used were those most easily obtained, and they varied as a result. To make such channels in the pre-pipe era required large stones, or boulders, or hewn stone, which were used where they occurred naturally. Where they did not, bricks were the obvious solution of the problem. Where stones were abundant in the soil and in arable farming, on the surface too, it was not surprising to find that stone-filled drains were used. In clay and silt areas, where neither solid rock might be accessible nor surface stones abundant, all sorts of adventitious fillings were employed in conjunction with a method of constructing the drains which exploited to the full the natural plasticity and cohesion of the subsoil material. Thus, in the clay lands of the eastern counties there were in widespread use two main methods, the hand-dug channel, narrow at the base, with a filling of straw rope, thorns, bushes or similar material; and the mechanically made channel known as the mole drain.

Early Drainage Systems. As the enclosure of land proceeded, a network of ditches developed to the increasing benefit of field drainage. Many of them were natural watercourses, but from them were dug side ditches at convenient intervals to divide the land into suitable plots for working and at the same time to take the drainage water away from them. Many were sited along lines vital from the point of view both of soil and drainage conditions. It frequently happens that such ditches coincide with the boundary between the exposures of two adjacent geological formations, as a consequence of the farmers' realisation that the soil and drainage conditions were different on the two sides of the line. Ditches, whether natural or artificial, are the most important feature of our field drainage system.

Joseph Elkington. During the latter half of the eighteenth century a Warwickshire farmer, Joseph Elkington, became widely known for his success in dealing with wet springy areas lying across slopes. He had studied the problem very closely on his own farm at Princethorp and appreciated the significance of the geological structure of the ground in this connection. It is not uncommon, along the sides of valleys, to find that there are alternating exposures of sand and clay under the surface soil. Where this happens, spring lines are almost certain to be found, brought about through the percolating water being forced out on the surface along those lines to the detriment of a belt of land lying below them. Elkington's method of dealing with them was to site a deep drainage channel across the slope where the water first issued from the ground, i.e. towards the top side of the wet area. Sometimes it took the form of a deep ditch, but often it was a deep, covered channel constructed in stone. It was always deep, however, to prevent the underground water from rising to the surface to be a nuisance. It was not an extensive formal system to remove the water from all parts of the wet area, but a single channel to intercept the water as it moved along the floor which was forcing it to the surface. This method was widely and successfully employed, on Elkington's advice, in many parts of the country.

Smith of Deanston. The method advocated by Elkington was not of universal applicability. James Smith of Deanston applied himself to the problem of the extensive areas of heavy land which because of its poor permeability was unable to get rid of the excess of water falling on it as rain, land which was prone to lie wet all over, in greater or less degree, during the winter and spring months. His solution was to install an intensive system of underground channels in a formal pattern, covering the whole field, to collect and lead the surplus water to a limited number of outfalls in the ditches. The channels were hand-dug and filled with small or broken stones to within 18 in. of the surface. He himself was not satisfied even with this, and proceeded on his own farm to make it work more effectively by carrying out subsoiling operations behind his ploughs. The production of drain tiles cheaply and on an extensive scale in England from the early years of the nineteenth century, enabled his method to be applied in principle all over the country.

Josiah Parkes. Meanwhile, in those regions which were low-lying and occupied by less heavy soils, Josiah Parkes had become convinced of the need for deeper systems of drains, laid to a formal and uniform pattern to prevent the accumulation of ground water and its rise from below.

Thus, a number of different methods of field drainage came into being and were applied, in the main correctly, in those parts of the country to which they were best suited, and by their means practically the whole of the agricultural land of this country was drained, where necessary, before the 1880's.

Diagnosing Drainage Troubles. It is important to remember this in approaching field drainage problems today. Many of them arise out of the neglect to maintain the existing systems, but some are due to faulty planning or faulty work when the job was first tackled. If not regularly attended to, ditches soon begin to be obstructed by weed growth, collapse of the sides, fallen boughs, broken culverts under gateways and so on. They begin to silt up, the outfalls are submerged and silted over, the pipe-lines behind them cease to function, bursts occur and water breaks out over the surface. In some circumstances trouble occurs which cannot be attributed to the state of the ditches. The passage of time or natural factors may put underdrains out of action. Such are silting attributable to the nature of the soil ; the deposition by chemical action of lime or iron compounds from certain soil types ; the settling down of the back-filling over the pipes in clay land ; or the entry of roots into them. Few drainage systems can be said to be permanent in the sense of complete efficiency.

Before carrying out any infield drainage work it is worth while to study carefully the problem of the wetness to avoid unnecessary expense and to obtain the maximum benefit to the land in question. A knowledge of the geological build of the country and the situation of the affected area relative to its surroundings should give a fair idea of the fundamental difficulties ; whether they belong, for instance, to the nature of soil and subsoil or to the site. This done, the condition of past works should come under review, beginning with the ditches. All of them are important. On sloping land the function of the top ditch is to protect the field from the drainage of the land lying above it, that on the sides to carry it safely away, and that along the bottom generally to receive and evacuate the drainage of the field itself. The existence of obstacles, the extent of silting and the location and examination of outfalls is important, so that a reasonable assessment of the efficiency of existing installations can be made as well as of the chances of their functioning effectively once more. Next the internal condition of the pipe-lines should be ascertained, particularly in respect of silting and the possibility of clearing them. The drainage characteristics of the soil, the condition of existing drains and the cause of local wet areas, other than obvious bursts and overflows, can best be ascertained by digging holes at appropriate points.

Proceeding on these lines a reasonable diagnosis can be made and the most effective remedial measures can be planned accordingly. One's natural impulse is to concentrate attention on the wet area and devise means to take the water away. There is no particular difficulty about that, but the real problem is to prevent the wetness from recurring, i.e. to stop the water from getting there. To do that involves a knowledge of whence and how the water comes, which calls for a study of the wet area in its context of soil and site in the field, and of the field relative to its neighbours.

DITCHES

It is not often that new ditches are dug in this country ; more frequently, indeed, their elimination is contemplated because the mechanisation of tillages and the general increase in the use of large machines calls for bigger fields and there is often a desire to get rid of these obstacles to cultivational operations. It is not an act of husbandry to be encouraged. It is true that ditches can be successfully piped, but the job needs to be done carefully and well. The various functions of ditches, such as those of interception, draining and dealing with run-off, have already been described. The first two call for depth rather than width and this can be attained with no loss of ground by means of a piped channel of adequate size. The third function, above all, demands a big carrying capacity, i.e. both depth and width. Accordingly, in making, restoring, maintaining or piping ditches, it is important to appreciate to the full the purpose which any individual ditch serves. In the past it was not uncommon in the systematic draining of large agricultural estates to carry the efflux underground for quite considerable distances to the outfalls by means of commodious brick or stonework sewers in place of open ditches. Many of them are still sound and functioning. But this is a different matter from putting a line of pipes in the bottom of a ditch and filling-in over them. The feasibility of piping any ditch should be considered in the light of its function and the amount of water which it may be called upon to carry.

An existing ditch even when " bottomed out " does not make an ideal bed for a line of pipes. These ought never to be less than 6 in. diameter, and the actual size should be sufficient to deal with the rate of flow to be expected from the area of land whose run-off the ditch carries. All existing drains emptying into the ditch will need to be connected up to the new pipe-line, and if they are of major importance they should be led into it at a suitable and properly constructed sump. The inlet end of a piped ditch should be fitted with a grid to prevent the entry of floating debris. One danger associated with piped ditches is that those carrying water the whole of the year round may have a fatal attraction for the roots of plants growing above them and it is not unknown for such drains to become choked by the roots of agricultural crops.

Those ditches which run continuously are for the most part natural streams or their canalised successors, and as a result are of some size, are winding rather than straight and have, as a rule, trees growing alongside. They are spring fed. Others are entirely artificial and straight ; these run along the contours or directly down the slopes, to function as convenient field boundaries, as drains in themselves and as recipients of outfalls from the fields which they skirt. The dimensions of all should be adequate for their duties. Fortunately, other considerations also operate to attain this end.

The lack of stability of an exposed soil face under the influence of weather, treading and erosion, is countered by giving ditch-sides a slope or batter. The amount varies in practice, a common one being to cut the top edge back 1 ft. for every 2 ft. of depth (1 on 2). The bottom of a ditch needs to be wide enough to accommodate the feet of the men working in it and a minimum of 15 in. is desirable. Where possible, the inverts of outfalls should be higher than the floor of the ditch, so that in few circumstances is there justification for depths of less than 3 ft. A good working rule is to make the top width equal to the depth plus the bottom width, the depth being decided by that of the outfalls or the draining effect to be achieved by the ditch itself, and the width by the amount of water to be carried.

Avoidance of irregularities in the conformation of a ditch is obviously desirable. There should be no constrictions, no sudden turns, no marked or rapid changes in grade, because all these lead to localised erosion and silting. The stability of ditch-sides is a matter of importance. Weathering and crumbling are natural occurrences and the most effective preventive is a cover of the indigenous herbage, hedgerow shrubs, grass and weeds. In reconditioning ditches it is as well to bear this in mind and to avoid unnecessarily flaying off such sod as exists on the ditch-sides. This is a point of importance in ditch maintenance, when silt is being removed from the ditch floor and the annual growth of weeds is being " brushed out ". When the job amounts to a thorough bottoming-out, however, the amount of material to be removed in order to uncover the original ditch bottom and the outfalls of old drain systems entails drastic treatment of at least one side. This type of work can now be done quite efficiently in ordinary field ditches by means of one of the varied range of ditch-clearing machines which have been developed in recent years (see Plate XVIII).

In all ditching operations, care should be taken to discover, liberate, and render effective any outfalls which may exist. The disposal of spoil from the ditches presents a problem which, if neglected, may cause an amount of trouble and nuisance which seriously offsets the advantage accruing to the drainage. Its amount, nature and condition may all present problems, but it should be deposited in such a way that it does not fall back, nor get trodden or washed back into the ditch, that it does not interfere with surface drainage into the ditch, that its weight and wetness do not cause the berm to collapse, and finally so that it does not dry and set in irregular heaps and banks which are difficult to spread, which harbour weeds, and which are an obstacle to cultivations and cropping.

Culverts are an important item of equipment in ditches, as is testified by the original and common practice of building them substantially in bricks or masonry. The casual and makeshift measures so common in the immediate pre-war times caused much more trouble and depreciation in the drainage condition of our agricultural land than is generally realised. Culverts should be commodious and well built, with the floor on a level with the original bottom of the ditch, wide enough to carry all the water brought to them, without causing substantial backing-up of water on the high side, and strong enough and sufficiently well finished not to come to grief under the traffic which crosses them.

TILE DRAINING

In considering the practice of tile draining it is essential to have in mind the salient points of soil moisture relationships, and the way in which water moves in the soil, as outlined on pages 13 and 37. The conditions in which harmful water-logging occurs and with which farmers' drainage problems are commonly associated may be grouped into five classes :

1. " Bottom water ", or a rising water table due to an impermeable stratum below a soil of open texture or structure.
2. " Top water ", or surface water-logging due to the impermeability of the immediate subsoil, e.g. clay land.
3. A combination of (1) and (2), as found in heavy silts and heavy subsoils other than clay.
4. Springs or spring lines at the division between permeable and impermeable geological strata on slopes or hillsides.
5. Ground water rising from below in valleys in permeable geological formations as a result of hydrostatic pressure operating from a distance.

Each of these various problems calls for its appropriate solution. The first is best dealt with by a system of parallel pipe-lines running with the fall if this is slight, or from ditch to ditch if the land is flat. A " gridiron " is a fitting description, whether each line of pipes has its own outfall or whether a number of them are linked by a main along the bottom of the field leading to a common outfall.

The second problem calls for similar treatment in principle, though the drain lines may be either pipes or mole channels. When, however, the fall is pronounced, the herringbone system with pipes has definite advantages in exploiting the downhill drift of water which is natural in such circumstances. As will be seen later in discussing mole draining, this is a point of some importance.

The third type of problem will be found to be amenable to the principles applied for (1) and (2) with appropriate intensification in the manner so " thoroughly " executed and expounded by James Smith.

The fourth problem constitutes the subject of Joseph Elkington's many triumphs. His method was to elucidate the lie and exact position of the troublesome clay stratum involved and to site a deep ditch or a deep commodious underdrain just on the high side of the critical spring line, reaching down to the impermeable floor and leading to a convenient side ditch, or by means of a main, to the ditch at the bottom of the field. Such deep drains operate by intercepting the water moving along the impermeable floor before it comes out at the surface.

The fifth type of problem is probably the most difficult to deal with, since the water is rising from below rather than moving in laterally, and interception in the simple sense of the term is not easily accomplished. Areas thus circumstanced are fortunately restricted and their subjugation is not often attempted. To do so effectively involves difficult and expensive operations in the way of laying deep parallel drains, which must first start to function as ditches, later to be piped and filled in. Here again an effective outfall is essential to achieve the requisite depth for the pipe lines, no easy matter in the general topographical conditions in which this particular problem is encountered.

Depth and Distance Apart of Drains. A hundred years ago shallow draining meant channels at a depth of about 30 in. and an interval of a rod (5½ yd.) ; it was practised for the most part on heavy land. In deep open soils, by contrast, depths of about 4 ft. and intervals of about a chain (22 yd.) were frequently employed. Later there was a regrettable tendency in some districts to lay pipes in clay at very shallow depths, 20 in. or even 18 in. This is excessively shallow work and soils which are so tough and impermeable as to warrant it would be much better dealt with by means of a mole plough, which in good practice is operated at 20–24 in. depth and about 3 yd. intervals.

Depth and distance in draining are decided by what is feasible in the circumstances and what is desirable for particular farming purposes. To be early, land must be drained very well indeed ; and when one finds it achieved artificially, it is generally by the deep draining of open soils. As a case in point there may be quoted some light silt soils of the Fens, with drains from ditch to ditch across the field, laid 6 ft. deep and 2 chains apart. Such are the circumstances in which permeability can be exploited to the full. But the lower the permeability of the soil mass, the closer and shallower it becomes necessary to lay the pipe-lines, and the less feasible it becomes to compensate for wide intervals by greater depth. A different factor becomes important ; the surplus water is more and more a feature of the top soil, in which it moves until it comes to the more open material over a pipe-line, to which it thus obtains easier access. It is in the heavier soils other than true clays that depths of 24–30 in. and intervals of 1, 2 or 3 rods are found justifiable.

Drain Pipes. Up to the present time land drain pipes have been made mostly either of clay or concrete—in agricultural field work clay pipes have been almost universally employed. The deciding factor is cost, so long as the pipes are reasonably sound, uniform and durable. Some 150 years of experience and experiment have eliminated a multitude of specialised shapes and forms in favour of the cylindrical clay pipe, 12 in. long, easily handled and comparatively cheap to produce. There is a limit to the diameter and length of drain pipes made with clay, but concrete is successfully used for making larger pipes and is the best material for pipes over 8 in. in diameter and 2 ft. in length.

The use of pipes of small diameter should be avoided, because of the ease with which they get displaced in the ground with the result that the continuity of the channel is broken : 2½ or 3 in. is a desirable minimum internal diameter. Otherwise, carrying capacity and the area of land served should decide the size of pipes used. In this country a 3-in. pipe should deal adequately with the run-off from 3 acres of light land, or 2 of heavy land ; a 4-in. pipe should serve 7 acres of light or 5 acres of heavy land ; a 6-in. pipe should serve 18–20 acres of light land.

Laying the Pipes. At the outbreak of war in 1939 there were not many skilled hand drainers in existence, but the amount of drainage work then required produced a new generation of drainers and also led to the appearance of a number of machines for excavating drain trenches, laying pipes and back-filling over them. Both hand work and machine work require skill to produce the best results, and in the execution of work a number of points should be kept in mind. The system should be marked out on the ground, the grades established, and the pipes laid out in such a way that they will not interfere with the digging and pipe-laying. The grades should be set up above ground by means of three or more horizontal bars for each length of drain line so that the level of the trench floor can be checked against them.

Work should begin at the outfall and proceed in such a fashion that the developing system can function if need be in case of heavy rain or tapping pent-up water. Excavated material should be placed tidily and systematically with the view of its easy replacement. The digging should be the minimum possible for the aim in view and the trench bottom should be completed by the scoop, with the floor undisturbed, and in such a way as to provide a bed, semicircular in cross-section, and of the right size to fit the pipes snugly. The pipes should be laid in succession from the outfall, properly butted-up end to end, and given a first cover of material calculated to remain open enough to allow percolation but close enough to prevent silting. The top soil may be the best material for this purpose and it is certainly the most easily obtained. The operation of blinding, or giving the pipes their first few inches of cover, is particularly important before back-filling by machine, and in trench bottoms which do not fit close to the pipes, to avoid displacing them. Junctions of minors with mains, and of submains with mains must be made with care to avoid silting, erosion, collapse or bursting. According to their importance and to the loads anticipated they may range from hand-made pipe joints (one being let into the side of the other) to specially prefabricated Y-pipes, or brick chambers with a covering slab for more important junctions.

The chief difficulty with outfalls is to render them stable and secure. The best cheap method is to use a scrap-metal pipe of the right diameter, 5 or more feet long, placing it so that it achieves stability by the combination of a smooth tight bed and a well-tamped back-fill over it. Alternatively, the pipe-line can be made to terminate in a socketed glazed pipe laid in concrete, with a surrounding brick or concrete headwall built to the batter of the ditch-side and supplemented by an apron of similar material under it and also on the opposite side of the ditch to prevent erosion.

It has been pointed out that most fields have been drained before and that frequently the drains can be brought into action again. Where, nevertheless, it is decided to redrain and it is found that old pipe-lines are being broken into by the new, the old line should be appropriately joined up with the new so that if it still functions it will have an adequate outlet.

MOLE DRAINING

Clay land farmers, struggling against the seasonal wetness which is a natural characteristic of their soils, have for centuries exploited the plasticity and tenacity of clay in their field drainage operations, producing by hand or by machine underdrainage channels which would last and function for a number of years without the aid of pipes or other rigid lining materials. An account of one of these, known as plug draining, was given by Stephen Switzer in *The Practical Fruit Gardener*, published in 1724. Machines called mole ploughs were not uncommon in Essex at the beginning of the nineteenth century, and much that is of importance in the practice of mole draining is on record in Arthur Young's *Agriculture of Essex*, 1807.

The Mole Plough. The mole plough consists essentially of a chisel-pointed, horizontal, cylindrical mole affixed to the foot of a stout knife-edged vertical coulter, which in its turn is mounted in a long heavy beam so designed that it can be drawn along the ground by suitable power, with the mole moving through the subsoil at a set depth. At the rear of the mole is attached an expander, of greater diameter than the mole by ½–¾ in. (Plate IIIB). The beam is usually elaborated and slung from a frame mounted on wheels, so that it can be lifted out of action or lowered into position by a power unit on the tractor or a self-lift mechanism on the plough wheels. Mole ploughs are built to different designs and dimensions, but common agricultural use aims at a 3–4 in. channel 20–24 in. below the ground surface.

A mole plough moving over an uneven ground surface tends to produce an uneven channel unless there is some steadying influence or mechanism for smoothing out the irregularities. This is the function of the beam whose length and weight, in conjunction with a flexible attachment to the power unit and with the chisel-shaped leading end of the mole, combine to cause the mole to move horizontally through the subsoil and produce a smooth even channel. The action of a mole plough, which should travel at the rate of

2–2½ miles per hour, is to prize up the ground in its track in a systematic fashion and to leave behind it a smooth channel, circular or ovoid in vertical cross-section. The soil mass above the channel is left with frequent vertical fissures branching at an acute angle from the slit made by the coulter and joining it in the direction from which the plough has come. The ground is thus moved and opened on both sides of the slit to a total width of 4–5 ft. in the case of heavy mole ploughs. The slit and accompanying fissures let the water down to the mole channels which in turn lead it away.

It is important to ensure that the seating of the coulter in the frame and the set of the mole relative to the beam are maintained in such adjustment that the mole proceeds through the subsoil with its axis parallel to the ground surface, otherwise the action will be a tearing one and the channel will be distorted vertically, with rough broken walls and the roof much too close to the ground surface: in such conditions rapid and early collapse of the system will ensue.

Land Suitable for Mole Draining. Mole draining is eminently successful in clay land, and can be used effectively in most heavy land with stiff subsoils if carried out in the right way. The major clay formations in Great Britain are well defined and are mapped in detail by the Geological Survey. The land most suitable for mole draining is found on the exposures of the Gault, Ampthill, Oxford, Lias, Kimmeridge and London clays and on the Boulder Clay of the south-eastern half of England. There are also isolated areas of Boulder Clay and other clay formations suitable for mole draining in other parts of the country.

Land which is suitable for mole draining is characterised by even, unbroken surfaces and gentle slopes. It is hard and cloddy when dry, with marked fissuring in times of drought, sticky and tenacious when wet, and very prone to surface water-logging. The subsoils, on examination to 24–30 in. in depth, will be found to be dull in colour, generally buff, grey or blue-grey, with faint mottling of brown or buff. They contain few or no stones, and not much sand. In short, they show the properties of shrinkage, tenacity, plasticity, and impermeability to a marked degree. Sandy clays and heavy silts are less suitable subjects for mole draining, mainly because of their lack of stability which renders the mole channels prone to silting and to premature collapse.

Mole drains should be 3–4 in. in diameter, circular or nearly so in cross-section, 20–24 in. deep (to the floor of the channel), 8–12 ft. apart, and not much more than 10 chains in length. They should run with the fall as a rule, except where this is excessive. They should be drawn over a properly covered main or system of sub-mains, and should cover the whole of the field or area concerned in a uniform manner. In this way the subsoil will be rendered open and permeable (some $\frac{4}{9}$ of the area is actually moved or fissured) and surface water-logging is thus prevented, all excess of rain being rapidly carried away by the mole channels below. Mole systems in action work swiftly: the run is in the form of a flush and the outfall rates are very high—some 1,500 gallons per acre per hour have been recorded. Hence, to get rid of all this and to safeguard the mole system, it is advisable to use 4-in. pipes for the mains and to provide at least one outfall per 5 acres of land.

Obviously, the layout of mole drain systems depends on the size, dimensions and topography of the fields concerned. The simplest are those of roughly rectangular shape with a receiving ditch along the bottom side. A piped main is laid parallel to the ditch, about 15 yd. away from it, with leads to the ditch every 4–5 chains run. The moles are drawn over this main, parallel to the sides of the field, and any length up to 10 chains. For lengths exceeding this it is advisable to divide the run into two, by means of a second main across the field, so sited that it leads to a convenient side ditch, or to a carrier main to the ditch at the bottom of the field. The second main may have only one outfall and therefore may not be able to serve as much as half of the field. The aim in planning should be so to site all mains that it is possible for the mole plough to traverse the field, to and fro, without interruption, as simply as the ordinary plough. In land with poor falls, this may be attained by siting the pipe-lines in such "lows" as do occur, so long as they run more or less in the same direction. A field with a pronounced depression through it may call for moling either parallel to the trough and across the slopes, or at right angles to the trough, in which are laid two parallel mains some yards apart.

It is possible to mole drain at any time of the year, but circumstances render some months much more favourable than others. The surface should be dry enough to take the tractor without its slipping or digging in, and the subsoil should be moist enough to take the mole without excessive "bursting" effects. In this way the right degree of fissuring of the ground will accompany the production of a smooth-walled mole channel, likely to last its full time. There should not be water standing about when moling is in progress, nor should the land even be wet, if it can be avoided. On the other hand, a drought-hardened subsoil, though maybe desirable for drastic subsoiling or bursting operations, is not in the best condition for successful moling. Corn crops and leys suffer little harm from moling carried out in favourable soil conditions, so long as they are not in full growth. The best months for moling will be found to be March to June, with July to October also good, except in droughty summers. In the winter months the soil conditions are frequently unsuitable.

Mole Drains and Main Drains. The provision of a proper main is essential to success in mole draining. It is possible to draw moles direct from a ditch and have some of them function, but they soon collapse and go out of use. The ends can be piped to keep them open, but this practice is wasteful and inefficient and does not overcome other weak points such as the damage done to the ditch by the mole plough, the loss of time, and the cost. With a moderate expenditure per acre on a really good piped main, a durable foundation can be obtained which will serve for an indefinite number of repetitions of the moling at intervals of a few years at its own characteristic low cost. The main should be laid according to sound tile draining practice at such a depth that the mole plough has easy clearance of the pipe. The excavated trench, being in clay, should be as narrow as it can be made, both to provide a tight firm bed for the pipes, and to economise in the covering material which must be put over the pipes up to a level well above that of the roof of the mole channels. The function of this cover is to let the water from the moles down to the pipe-line. It generally takes the form of the most abundant material of an open nature which is to hand, e.g. bushes, hedge cuttings, coarse clinker, coarse gravel, broken tiles, rubble, shells. Bushes and clippings should be carefully trodden in; the other materials should not contain any quantity of very fine particles, to avoid risk of silting.

There is room for discrimination in the time when the main should be laid. The best time is probably immediately after moling, if this is done in summer in the most favourable conditions, especially if the digging is done by hand. It is inadvisable, however, to risk having the moles run in the absence of a main. Another sound method is to lay the mains a year before moling so that the trench-filling becomes consolidated before moling takes place. If moling follows shortly after main laying there are distinctly greater chances of harmful disturbance of cover such as bushes, and of the sides of the trench, to the detriment of the mole channel-main connections.

Occasionally circumstances arise in which moled mains can be used. This is not very good practice and is only justified on a short term view. Points to bear in mind are (1) to draw three or four channels for the main, at least 3 yd. apart and at sufficient depth to give them 1 or 2 in. clearance of the floor of the minors; (2) to " eye " all of them into tiled leads on the same level, one lead per 3 acres; (3) to draw the mains before the minors.

Duration and Cost of Mole Drains. Mole draining properly carried out in the most suitable clays will function well for five or six years and will gradually peter out during the next five or six years. In prosperous times repetition every five years is well worth while. In less appropriate soil circumstances repetition after three years may be necessary. Over a proper piped main system this only entails the simple routine of the mole plough and its cost. It must be remembered that the success of moling depends as much on its fissuring of the subsoil as on the creation of a channel. The former gradually disappears while the latter steadily decays and collapses. Moling should be viewed as a periodical cultivation, with the conventional mains as the permanent basis for this cultivation.

Moling commonly costs less per acre than the chain length of 4 in. tiled main which can be found servicing such an acre. When this is compared with the costs of thorough tile draining in heavy land, the advantages and possibilities of mole draining are very clear, for it must be admitted that the experience of clay land farmers with tiled systems has not been satisfactory except in the early years after installation. This is reflected in the constant and widespread use of moling in our clay areas and the increasing utilisation of the method with suitable modifications in less heavy types of land. Mole-cum-tile systems are the logical development, combining the lasting qualities of tiled systems on a less intense and costly scale, with a longer life as a result of the superincumbent open filling, and with the cultivational and revivifying effects of mole draining, repeated as and when necessary at a low cost. In this way tile draining at 2–5 chain intervals can be made to work.

SURFACE DRAINING

The old and widespread practice of setting-up the land in ridge and furrow or in high-backed lands was essentially surface draining. It survives still in much of our permanent grass land and in certain localities in the use of the narrow stetch in heavy arable land. The London Clay areas of Essex provide an important example. In both systems the furrows function as surface drains for the lands, stetches or ridges and their layout conforms to orthodox draining practice. On sloping land the ridges run with the fall and the furrows lead to a master furrow running at right angles to them at the bottom of the field with surface leads to the ditch at appropriate intervals. Sometimes these leads take the form of tiled or covered channels through the intervening ridge. In stetch work it is common practice on completion of autumn sowing to plough out cross-furrows on a suitable plan to collect the water running down those between the stetches. The junctions are cleared and perfected by hand. The layout on slopes may result in a limited number of such furrows running diagonally across the field to suitable outfalls into the ditches. On flat land it may result in the stetches being split up into beds by more numerous furrows drawn at regular intervals at right angles to the stetches and opening into the ditch at either end. The principles of the method can be very profitably applied to any heavy land field, immediately after autumn sowing, if there is reason to suppose that the drainage of the field is defective. Thereby excessive water-logging in a wet winter may be avoided, with substantial benefit to the crop occupying the ground.

The same principles used to be, and still are, employed on moorland grazing in the guise of sheep drains. These consist of shallow hand-dug surface drains in the peat, laid out in what may be described as extensive, sparse, herring-bone systems on the slopes, leading to the natural burns or becks. This practice had to a large extent died out before the war, but the innovation of heavy and powerful draining ploughs or sheep-drainers has opened up encouraging possibilities of substantial improvement of our moorland grazings by this means.

Chapter III

BUILDINGS AND OTHER FIXED EQUIPMENT

MANY of the farmsteads and their buildings in existence today were first erected at some date between 1800 and 1875. The enclosure of the open fields, which had been going on gradually for several centuries, became much more rapid in the last quarter of the eighteenth century until well on in the nineteenth century and resulted in the creation of large numbers of new farms which had to be equipped with buildings. At the same time farming methods made great advances, and the ramshackle, draughty buildings of the eighteenth century, constructed of local materials such as timber, stone and thatch, no longer met requirements, particularly for livestock which were being housed through the winter.

Development in the design of farm buildings went rapidly ahead, encouraged by such writers as J. C. Loudon with his *Encyclopaedia of Cottage, Farm and Villa Architecture*, published in 1836 and J. Bailey Denton's famous *Farm Homesteads of England* which appeared in 1863. New and more durable materials were used, since with improved communications building materials could be transported further afield. Bricks became more widely used, iron roof trusses were developed and roofs were covered in tiles or slates brought from Wales or the North. The buildings were substantially constructed and for this reason so many have survived until the present day. By modern standards, however, the livestock buildings appear cramped and stuffy, wagon sheds do not meet the needs of modern machinery; the large enclosed barns are awkward for storing hay and straw and too little account was taken of the ways in which labour might be saved.

When the so-called Golden Age of Farming had come to an end about 1875 rents slumped and had fallen by about a third at the end of the century. Landlords were no longer willing to invest capital in farm buildings and progress stopped. With farming in a depressed state rents remained low for the next forty to fifty years. Few new buildings were erected and they were mainly such inexpensive structures as dutch barns, and Scandinavian piggeries which first appeared about this time. There was a marked swing to dairying, bringing a large increase in the number of tie-up cowhouses, but these were provided mostly by adapting existing buildings as cheaply as possible. Two relatively inexpensive materials also first started to be used in the 1920's, concrete for floors and walls, and asbestos-cement sheeting for roofs. With expenditure on fixed equipment being so limited there was little opportunity for the development of new ideas in design and in materials for farm buildings.

By 1939 farm buildings as a whole were out of date and were often in poor condition as well. The wartime National Farm Survey of England and Wales of 1941-43 revealed that 61 per cent of farmsteads had buildings which were technically unsatisfactory. Although in the 1939-45 war there was rapid progress in new farming methods little could be done to improve farm buildings. Since the war the revolution in farming methods has continued and has had a counterpart in the design and construction of farm buildings.

The development of new designs and materials for farm buildings, testing them out under farm conditions and then getting the new developments widely adopted, is inevitably a slow process. It is a far slower process and involves much higher expenditure than the bringing into use of most new techniques in farming. Because of this the progress with fixed equipment of farms, though very considerable, has been inclined to lag behind farming progress generally, and at times the lack of satisfactory fixed equipment has tended to impede the general advance of the industry.

To encourage the injection of more capital into the improvement of fixed equipment various forms of Government assistance have been available since the war. In 1946 a scheme was started for giving grants of half the cost of reconditioning hill farms, particularly for work on the buildings, and this was extended in 1951 to upland farms depending on livestock rearing. In 1957 the Government launched the Farm Improvement Scheme under which grants of one-third of the cost were made available for new and improved buildings and other permanent equipment on all types of farm. A sum of £50 million spread over ten years was made available.

Planning and Building Controls. Farm buildings, but not farm houses and cottages, can be put up or altered without the need to obtain any permission from a local planning authority provided that, in the case of a new building, it does not exceed 5,000 sq. ft. in ground area either by itself or added to other buildings erected within 100 yds. during the preceding two years. There are a few other exceptions, and there are special arrangements in force for areas of " Special Scenic Beauty ". In case of doubt the local authority should be consulted.

Most local authorities have in force building by-laws requiring plans and details to be deposited before new building work or reconstruction is carried out, particularly anything affecting drainage systems. There are also restrictions on the sinking of wells and boreholes and the storage of more than 3 gallons of petrol. In addition there are regulations made under the Agriculture (Safety, Health and Welfare Provisions) Act, 1956, about structural precautions to be taken to safeguard apertures, stairways, pits and stationary machinery in farm buildings. Details of all these controls can be obtained from local authorities.

MODERN DESIGN AND BUILDING MATERIALS

With building costs rising steadily until they are now three or four times what they were in 1939, the aim in design has been to have durable buildings suitable for their purpose, but at the lowest possible capital cost and constructed of materials requiring little or no maintenance. As a result, traditional buildings of brick and tile, or stone and slate, constructed to fit the site are being superseded by framed structures bought prefabricated from the manufacturer. This type of building comprises basically a framework spaced at 10-15 ft. intervals, supporting a roof which is covered in light sheeting. Walls, where required, are in the form of infilling panels, carrying no load from the roof. The framework can be either stanchions or pillars to which built-up roof trusses are fixed, or a " portal " or arch frame (see Fig. 16). The portal frame has the advantage of requiring no tie beams or other obstructions. Wide spans are possible with framed buildings, without the need for intervening stanchions to obstruct the floor space. Upper floors are more costly to provide than ground floors, and two-storey buildings are not often erected, except for such purposes as granaries where gravity can simplify the movement of foodstuffs and other materials. Roof lights are preferred to windows in walls because overhead lighting is usually more effective and less likely to be damaged. Flat roofs are also being used instead of lean-to or pitched roofs for small buildings such as dairies. With a simple structure of timber, covered with asphalt or felt laid by a specialist firm, this type of roof need not be expensive.

Roofing. Corrugated sheeting of various materials is used for roof coverings and walls ; it has the advantage of being light, weatherproof and reasonably durable. Asbestos-cement requires no maintenance but is brittle, and should not be used in places where it may be knocked, such as the lower parts of walls, or where the building itself may move. Galvanised steel costs about the same and is better in such places though the galvanising wears off in time, particularly if used in livestock buildings where condensation occurs, and the sheets then have to be painted periodically. Aluminium and plastic sheets are also available and while more expensive they are not fragile and need no maintenance. Transparent plastic and resin bonded glass fibre sheeting, in corrugations to match other types of sheet, provide weatherproof roof lighting.

Concrete. For livestock buildings, reinforced concrete is probably the most suitable material for the structure, taking into account cost and durability without maintenance. It is available in the form of structural frames, roof trusses, window frames, beams and joists for upper floors, water troughs, rain-water gutters, drain pipes and chambers. Concrete components tend to be clumsy and heavy, but pre-stressed concrete is an improvement. It is reinforced concrete in which high tensile wire takes the place of mild steel rods, with a considerable saving in weight.

Steel. Steelwork is lighter and smaller in section than concrete and is easier to transport and handle on the farm. It needs painting, except in smaller components such as window frames which should be bought galvanised.

Timber. Timber is expensive and should be used economically. With modern techniques using graded timber and metal connectors and plates to simplify and strengthen joints, lighter and shorter lengths of timber can be used for structural purposes. The Timber Development Association has developed a number of designs of simple timber frame which can be constructed on the farm (see Fig. 2).

Protection. Metal must be protected from corrosion, and timber from the effects of damp, fungi and insects. A film of paint will pre-

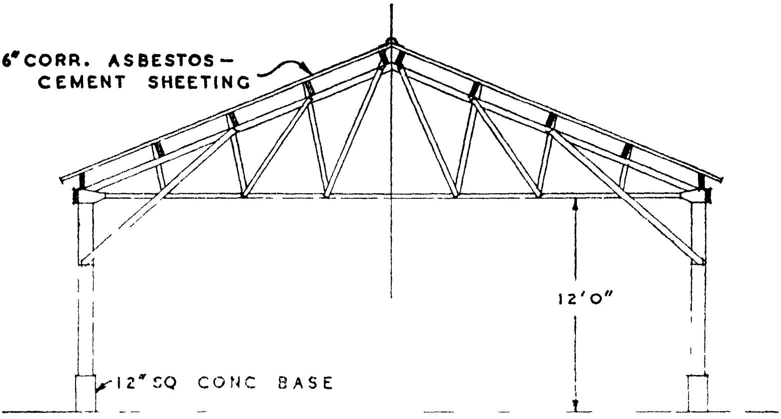


FIG. 2.—TIMBER IMPLEMENT SHED DESIGNED BY THE TIMBER DEVELOPMENT ASSOCIATION.

vent damage by damp though repainting is essential before the film perishes. Oil paints are expensive for farm buildings: tar, and bitumen paints are much cheaper for timber and metal but equally satisfactory though they are dark in colour. The best forms of these paints are bitumen solution paint and black paint (tar base). Timber can also be treated with preservatives, and whilst these will not prevent it becoming damp and swelling they stop any attack by fungi, such as dry rot, and insects. Preservatives are cheaper than paints and should be used for timber farm buildings and all timber in contact with the ground, such as fencing posts. Creosote is the cheapest form of preservative but it has a smell causing taints and it is unpleasant to handle. There are inexpensive water-soluble preservatives which can be used instead ; they are usually sold under proprietary names. It is often possible, and an advantage, to buy timber which has already been treated with preservative.

Walls. For walling there is little to choose between concrete blocks and brickwork ; blocks are probably easier for unskilled labour to use but to avoid trouble with cracks there should be very little cement in the mortar so as to allow for shrinkage movement. To be weatherproof, walls should be 9 in. thick and should have a damp-proof course just above the ground to prevent rising damp. Rain-water falling on roofs should be kept away from walls by using gutters and downpipes. Asbestos-cement is often used as it is inexpensive and requires no maintenance.

Floors. Concrete is the most suitable material for floors in most farm buildings, though in livestock buildings insulation is needed, as will be explained later. All concrete floors are improved by being made damp proof by incorporating a layer of bitumen in the concrete.

THE SITING AND LAYOUT OF THE FARMSTEAD

The ideal site for a farmstead should be sheltered, but not shut in by trees, and sloping slightly to the south away from the direction of

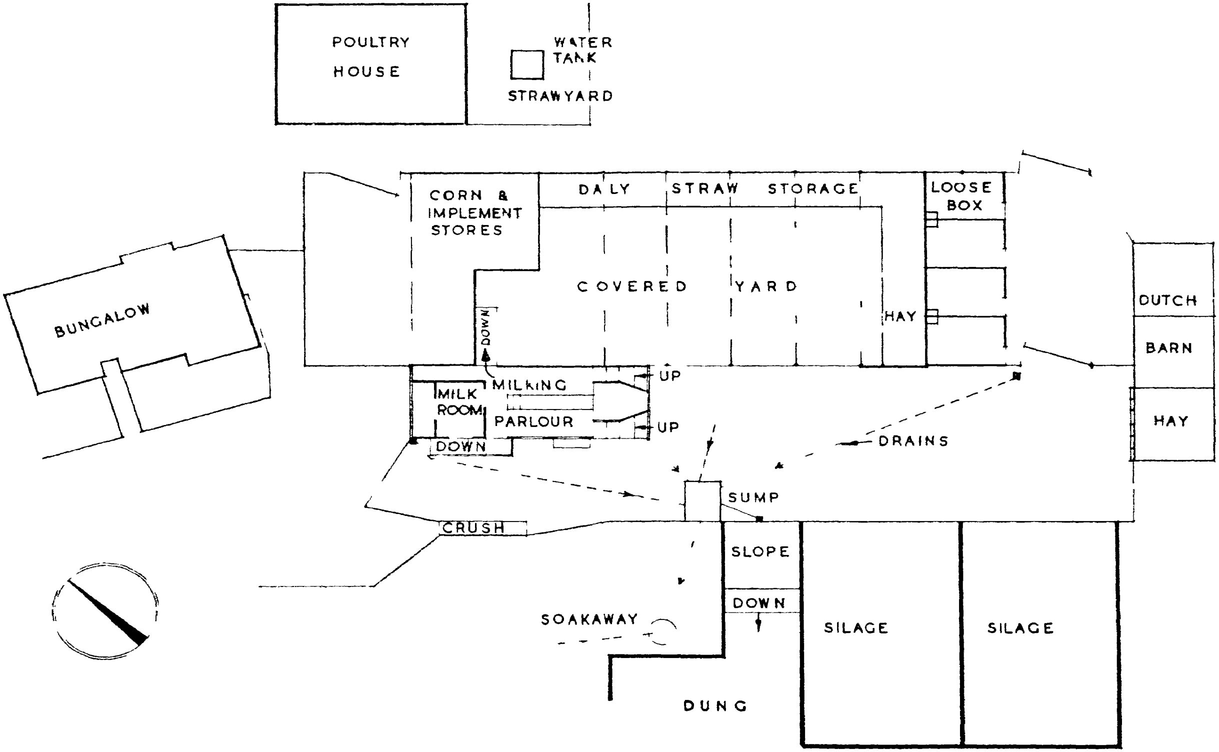


Fig 3 —Dairy Farmstead for 70 Acre Holding designed by the *Farmers' Weekly* at Bulborne, Hertfordshire

prevailing winds and rain. The slope should be sufficient to enable sewage and rainwater to be removed easily but not so great as to make building difficult. The soil should, ideally, be free draining. Easy access to a good, hard public road is important. With a small farm there is much to be said for a site adjoining the road, provided the site is otherwise suitable : but on the larger farm it may make for easier working to have the farmstead as near the centre of the farm land as possible with a private farm access road, though this should not be too long. Such services as piped water and electricity are most desirable, but if available on or near the farm they should not determine the site since they are relatively inexpensive to extend to a good site.

Convenient and easy working is probably the most important point making for a good layout of the farmstead. Large quantities of materials, mostly bulky, have to be transported to and from the farmstead from both the fields and from outside. There should be good wide roads between the buildings with plenty of room in which a tractor and trailer can be used. The buildings should be grouped so that routes for the different types of traffic are kept separate ; livestock should be kept away from transport with produce from the fields, and field traffic in turn should not block the way of lorries bringing fertilisers and foodstuffs or taking away milk. Buildings concerned with the delivery of materials, whether the farm dairy, the grain storage and drying plant, the fodder store or the midden stead should be placed so as to eliminate unnecessary handling and to reduce the distances for moving materials. Buildings in which related processes take place should be close together. Food stores should be near or combined with livestock buildings ; dairies should be close to where the cows are milked and accessible to a road; milking parlours should be near the yards, to the cows and the way in from the fields. Tractor and implement sheds should be together, and can be away from other buildings. Livestock buildings should face south : tall buildings, such as dutch barns, placed on the north side will provide shelter. Buildings should be arranged so that mechanical handling can be used, whether for the bringing of food or removal of dung. The siting of silos for the self feeding of silage should not be overlooked.

A lay-out for a small farm is shown in Fig. 3.

Saving Labour. Continually rising labour costs and a diminishing supply of farm workers are emphasising the need to make efficient use of labour and to eliminate drudgery. Although study of labour use has long been a common practice in industry the methods employed have only recently been applied to farm work.

Work Study, also known as *Time and Motion Study*, has two main branches likely to be of use in farming. The first, method or motion study, involves analysing and recording in a standard form methods and equipment used or to be used in the performance of work, followed by a critical examination in a specified form aimed at showing where improvements can be made. These improvements are generally found to be self-evident, though it is only after such a dispassionate study that they become so obvious. The alterations required in buildings and in equipment are frequently small though the resulting increase in efficiency may be large. For the best results, training and experience in work study are required ; but common sense and an elementary knowledge of the basic theory can often suggest valuable improvements in work routines.

While method study is probably most useful in showing improved ways of working in existing buildings, some general principles for saving labour have emerged which are of value when designing new buildings. The reduction of unnecessary movements, particularly walking about, is probably the most important. This can be achieved in such ways as :

(*a*) handling such materials as foodstuffs and manure in the largest possible quantities (e.g. barrows and trolleys instead of buckets) and having buildings suited for bulk handling with wide doors and level passages, and containing bulk tanks as for milk, grain, fertilisers and feeding-stuffs ;
(*b*) having close together those buildings and work areas where related operations are carried out (e.g. food stores close to the animals to be fed) ;
(*c*) arranging buildings for circular travel and avoiding " back tracking " ;
(*d*) keeping tools, machinery and services, such as water, close to where they are used.

The use of gravity and simple machinery can do a lot to reduce work and drudgery.

Work measurement, or time study, is another branch of work study of use in agriculture. It is concerned with determining the time required under specified conditions for carrying out different operations. The preparation of standard times is primarily a matter for experts but these times when available—and they are very few as yet—provide a valuable basis of comparison between ways of carrying out the same task using different specified equipment and buildings, e.g. milking in different types of milking parlours. Standard times can also show how efficiently a task is carried out on a particular farm judged by the time taken compared with the standard time.

GENERAL PURPOSE AND TEMPORARY BUILDINGS

Most farm buildings are constructed of materials which will last very many years—often longer than the need for which the buildings were first erected. There is, therefore, much to be said for having buildings which can be altered without excessive expense to meet changing requirements and changing methods, or to have buildings suitable for a number of purposes without the need for any structural alterations. From the point of view of adaptability there are many advantages in the wide span building which has few intervening stanchions to support the roof, and partition walls independent of the main structure which divide the building up as required. A building which provides merely a roof and walls, leaving the floor free for any use, is a variation. The covered stockyard, which can be used for cattle, pigs and poultry as required, is one example. Another is the dutch barn which, particularly if sheeted on one or more sides, is very adaptable and can be easily and cheaply extended by the addition of lean-tos. It can be used for storing hay and straw, covering silage pits or housing implements and livestock. Loose boxes, particularly on a small farm, will serve many purposes.

The building suitable for more than one purpose may suffer from the disadvantage of not being ideal for any one purpose, and in many circumstances the special purpose building is to be preferred since, being specially designed, it will provide better conditions for livestock or other uses and will be more labour saving. Against this must be put the initial cost, which is usually higher, and the fact that the capital invested in it may have to be written off over a much shorter period if it cannot easily be adapted to other uses.

With the high price of timber and many other materials, and costly labour, light temporary buildings are almost as expensive to erect as more permanent ones, particularly those of the prefabricated concrete type. It is possible, however, by using rough timber and straw to make some substantial economies with home-made buildings such as open or partly-covered cattle yards, lambing pens and shelters for breeding and store pigs. There are no fixed designs, but a little ingenuity and a frame of coppice poles or woodland thinnings, with straw in bales or sandwiched in netting, will make useful buildings. Fire risks are high and vermin can be a nuisance ; such buildings should be taken down before becoming derelict and an eye-sore. More ambitious buildings of the *pole-barn* type, shown in Plate LIXB, are also possible. A building tried out in this country comprises a framework of telegraph or similar poles and railway sleepers, supporting a roof of wire netting and roofing felt with walls of straw bales. Units of 40 ft. × 40 ft. have been found suitable for a wide range of livestock, including fattening and breeding pigs, and poultry.

VENTILATION AND INSULATION

Any enclosed building, particularly if totally enclosed, where livestock are housed for long periods, should have the air changed from time to time if the conditions in the building are to be satisfactory. Animals emit large quantities of carbon dioxide and moisture into the air and moisture may also be taken up by the air from floors, wet from washing down, from animal excreta, from drinking water and food. As a result the air in a livestock building will become humid and foul unless it is changed. Farm animals will not thrive in such an atmosphere, and the structure of the building may be seriously affected by the condensation which occurs when air, saturated with moisture, comes in contact with colder surfaces in the building.

Temperature. In addition to the affect of temperature on condensation it is important that the air in a building should be warm enough but not too warm for the animals. For cows, a temperature of 50°–55° F. is considered to be the best though their milk yield is little affected at much lower temperatures provided there are no sudden fluctuations. Pigs are less adaptable and need a more closely regulated temperature if they are to thrive. A temperature of 55°–65° F. is usually recommended for fattening pigs, and 65°–75° F.

for sows and young pigs. Farm buildings are not often heated artificially and any heat is supplied by the animals themselves. The amount can be considerable, and a 1,000 lb. dairy cow will give off 2,000-3,500 British Thermal Units per hour (3,412 B.T.U.s are equivalent to 1 kilowatt-hour of electrical energy). In winter the heat can, however, disappear rapidly from the building through excessive ventilation or by too rapid conduction through walls and roofs.

The cubic air space per animal should also not be too large since otherwise the animal will give out too little heat to warm the air in cold weather : 500-600 cu. ft. per cow and 50-80 cu. ft. per fattening pig are common standards.

Ventilation. Natural ventilation is all that is usually provided in farm buildings to change the air : it depends partly on wind which blows air in on one side of a building and sucks it out of the other, and partly on the fact that the air on being warmed expands, becomes lighter and therefore tends to rise. In a building it will rise to the highest point, normally the ridge, and if there is an outlet there it will pass out of the building and fresh, colder air will be drawn in from outside to replace it. The fresh air should be admitted through inlets in a position where it can quickly mix with the warm air without causing draughts. The quantity of air passing through the building should be sufficient to remove enough moisture to keep the relative humidity within the limits mentioned. If too large a quantity of air passes through during cold weather the temperature in the building will fall because the animals will be unable to heat the air fast enough.

Cowhouses. Experience has shown that to preserve satisfactory conditions in a cowhouse, each cow needs 2,400 cu. ft. of air per hour under normal conditions, increasing to about 6,000 cu. ft. in mild weather. This can generally be achieved with ventilation *outlets* at the ridge of 60-80 sq. in. per cow. The type of outlet will vary with the roof construction : for asbestos-cement sheets there is special ventilating ridge capping, or a 4 in. gap can be left between the sheets at the ridge, though this may cause down draughts in windy weather ; with slates or tiles, alternate ridge tiles can be raised. Patent extractor ventilators are also available. *Inlets* for fresh air need not be more than 9-12 sq. in. per cow at the most since a great deal of air will enter the building through windows and the opening of doors, which are also often badly fitting. Inlets should have a baffle to prevent wind blowing in and are best set at least half-way up an outer wall, spaced one to every two cows. Windows with hoppers which can be closed are an advantage, particularly in a gable end, as they provide a means of regulating the quantity of air entering the building. The quantity required will, of course, vary with the relative humidity and the temperature of the external and internal air, but with cattle, which can tolerate a fairly wide range of conditions, a close control of the ventilation is probably unnecessary.

Piggeries. As pigs require higher and more constant temperatures, piggeries should have a smaller cubic air space and the ventilation should be more controlled. It is found from experience that one of the most satisfactory designs of piggery has a flat, false ceiling over the pigs at eaves level with ventilation by means of a duct or flue, with an outlet which can be regulated in size, in each compartment of the piggery. A suitable design of flue is given in Fig. 14A. The quantity of fresh air recommended for a fattening pig of 200 lb. is 700–800 cu. ft. per hour in a totally enclosed piggery, or 300 cu. ft. in a house with outside runs for dunging. This can be provided by outlets or a flue of 8–12 sq. in. per pig and inlets about a half less. In partly enclosed buildings, such as covered yards or piggeries with outside runs, no provision for inlet ventilation is required but outlets are needed at the ridge. Natural ventilation requires suitable climatic conditions to be effective and electric fans are now sometimes used as a supplement when conditions are unfavourable. Fans are also used to provide all the ventilation in highly specialised piggeries.

Insulation. All building materials allow heat to pass through them to some extent. If a livestock building is to have a constant temperature in winter and summer and the ventilation system is to be satisfactory, with little condensation, either the materials of which the building is constructed must be resistant to the rapid transfer of heat or materials with good thermal insulation properties must be added to the structure as a lining. The materials in general use for roofs—asbestos-cement and corrugated iron sheeting—have a very poor insulation value and often need a special lining.

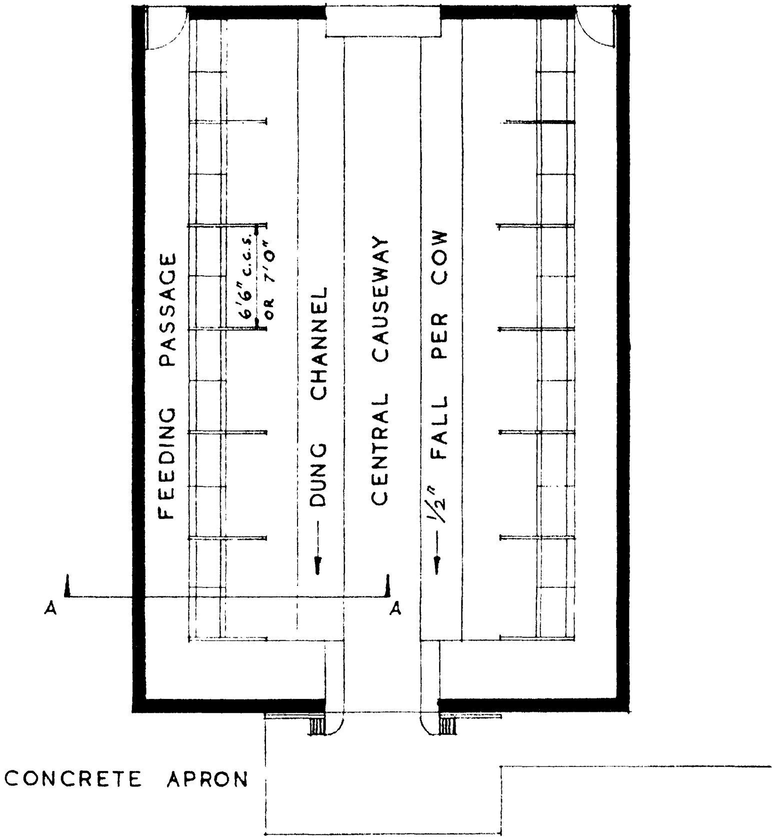
Air is excellent for insulation, and most materials used for insulation contain a large number of small air cells. The most suitable type of material will depend on the position in which it is to be used.

For roofs, the insulation can be in the form of boards or slabs of materials such as asbestos fibre, wood wool or compressed straw, fixed as an underlining just under the external covering of the roof or, as in piggeries, as a ceiling at eaves level. An alternative is to use loose materials, some available in a quilt, as asbestos fibre, glass and wood wool, or tightly packed straw supported on building boards or wire netting. To prevent the insulating materials being damaged by moisture passing through them and condensing on the cold surface of the outer roof, it is essential to seal the underlining against moisture penetration either by painting it with bitumen or aluminium paint, or by lining it with metal foil or waterproof building paper : any joints need to be watertight.

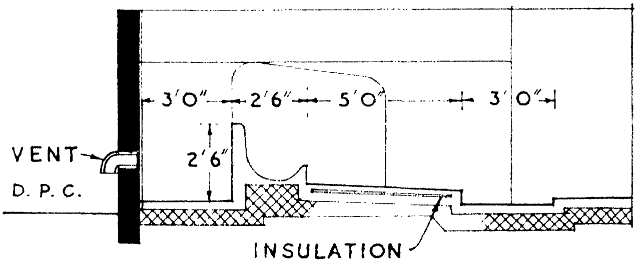
For walls a single leaf of 9 in. thick, hollow blocks, rendered externally if porous, or two leaves of 4½ in. thick brickwork with a 2 in. air cavity between provide a wall with adequate insulation properties for a livestock building. With thinner walls the insulation can be improved by adding an inner leaf of concrete blocks made with a lightweight aggregate.

Insulation is essential in concrete floors on which animals lie if they are to have a warm bed. The insulation is best provided by having a layer of material containing air spaces close to the surface of the concrete. Suitable materials are a 3 in. layer of concrete made with lightweight aggregate or with no fine aggregate as sand, known as " no fines " concrete (both these types of concrete contain air cells), hollow flooring or partition blocks, or 3 in. diameter field drains.

Moisture reduces the insulating properties of building materials and consequently it is important to see that as little damp as possible



PLAN



SECTION A·A

Fig. 4.—Double Range Cowhouse for 24 Cows.

gets into the structure of the building. Walls should be made reasonably resistant to rain, and floors as well as walls should have a damp-proof course to prevent moisture rising from the ground. Bitumen and bituminous felts are valuable for damp-proofing floors, and bituminous materials in rolls are also suitable for walls.

HOUSING THE DAIRY HERD

The design and construction of dairy buildings is affected by the Milk and Dairies Regulations, 1959, under which anyone producing milk for sale has to be registered by the Ministry of Agriculture and has to produce the milk in premises complying with certain requirements. Broadly these are that any buildings in which milk is produced, processed and stored, or cows are kept, have to be properly ventilated, lighted, provided with an adequate supply of clean water and situated where there is no risk of contamination of the milk. The access to a building where cows are housed but not milked has to be kept clear of dung, and the cows must be housed in conditions in which they can be kept clean. The buildings in which cows are milked should have an impervious floor wherever it may be soiled, and the floor sloped and provided with gutters or channels to take any liquid to a drain outside the building. The surfaces of the parts of the walls which may get soiled have also to be impervious and to be easily cleaned.

There are two main systems of keeping a dairy herd. In the first the cows are housed and milked in a *cowhouse*, *shippon* or *byre* in which they are tied in stalls : and in the second, cows are housed in yards which may be open, partly or totally covered, and are milked in a separate building, a *milking parlour*. The cowhouse system is the older and so is more common in the traditional dairying areas of the country, but the yard and parlour system has been rapidly gaining favour in recent years. There are many arguments in favour of each system : as regards capital costs there is little difference between a new cowhouse and a new covered yard and parlour, but it is more often possible to find buildings which can be adapted without great expense into a yard and parlour than into a cowhouse. A yard can also be used for other types of stock without any alteration, but it is difficult and expensive to adapt a cowhouse for other purposes. On the other hand, a cowhouse needs less space than a yard and parlour system and this can be important on a congested site. Experience has shown that there is little to choose between food consumption and milk yields of cows kept under the two systems, but with yards a great deal more straw is required for bedding. Cows are said to keep healthier in yards but, on the other hand, individual attention and rationing of food is more difficult. Considerably less labour in milking, feeding and cleaning out is used in a yard and parlour than in a cowhouse ; the difference, however, depends a great deal on the efficiency of the layout of the building and in the use of labour, but savings of 25–33 per cent are often quoted.

The Cowhouse. A cowhouse should be sited to be convenient for the dairy and food store and to provide a short and dry approach for the cows coming from the fields. There should be adequate space round the building so that the cows can get in and out without trouble and manure can be easily removed.

Cowhouses can be *single range* or *double range* ; in the latter, the cows stand back to back, separated by a central passage used when milking and for the removal of manure. Sometimes the cows face inwards on to a central feeding passage. For herds over 15 a double range cowhouse is to be preferred as it requires less labour and is cheaper to build, and for herds over 30 feeding passages are a worth while addition.

The following are the usual internal dimensions and details of construction of a cowhouse : they are also illustrated in Fig. 4.

Standings. These are the raised part of the concrete floor on which the cows are kept. The concrete should be insulated for comfort and slightly roughened to prevent slipping. The standings are usually 5 ft. long and arranged in pairs, 7 ft. wide for each pair. These dimensions can be varied slightly according to the size of the breed of cow.

Stall Divisions. The divisions separating each pair of cows can be of galvanised tubular steel or solid, to prevent draughts, in which case precast concrete, concrete blocks or cement rendered brickwork are the usual materials.

Mangers. There are wide variations in what is provided, from no mangers at all but a tiled area of floor in front of each cow to individual glazed troughs. It is essential that a manger should be capacious enough for the feeding of bulky fodders. The usual manger is of precast concrete or of concrete made *in situ* at least 2 ft. 6 in. wide and lined with a section of glazed stoneware pipe for durability and easy cleaning. Permanent or movable divisions in the mangers between each cow are desirable to prevent poaching of food. Automatic drinking bowls should be provided over the mangers.

Tyings. There are two types of tying, the central and the side tie. The central tie can either be a yoke or a double chain, which is usually preferred as it gives the cow more freedom. Side ties, fixed to stall divisions, are either single or double chains which can be adjusted to fit the cow. All ties should have a quick release arrangement.

Feeding Passages. Where provided passages should be 3 ft. 6 in. to 4 ft. wide to allow the use of a food trolley. There should also be no piers projecting from the outside walls into the passage and, to save walking, passages should go round the cowhouse without blind alleys at the end.

Dung Channels and Passages. The dung channel behind the standing should be not less than 2 ft. 6 in. wide and 3 ft. is better. It should also be 6 in. below the standing. The passage adjoining it should be as wide as possible and in a double range cowhouse at least 5 ft., so that a tractor and trailer or a tractor with a scoop can be used for cleaning out the building. In a single range cowhouse the passage should be 4 ft. wide. Passages can be continuous with the dung channel but it is better for them to be 2 in. higher. For the drainage to work satisfactorily, the whole floor should be carefully

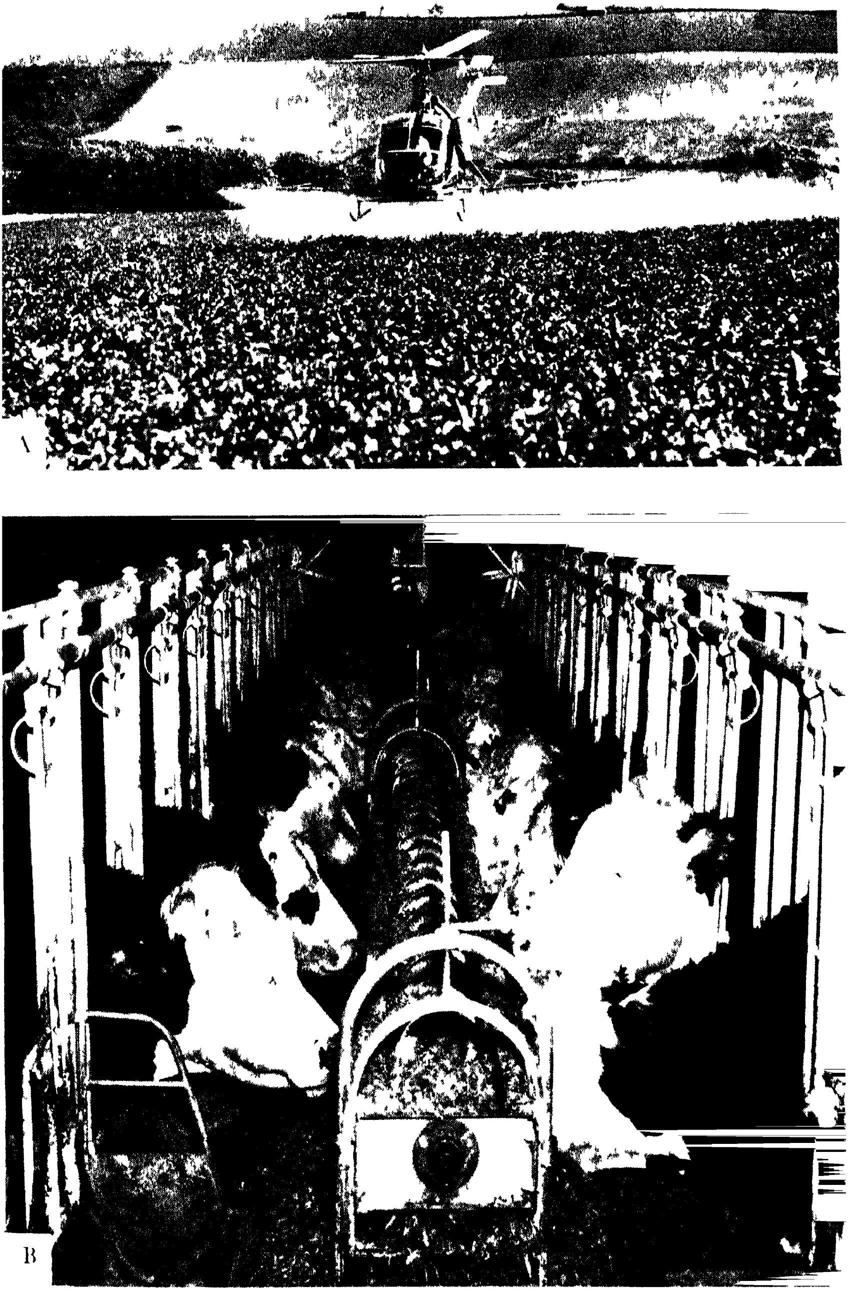
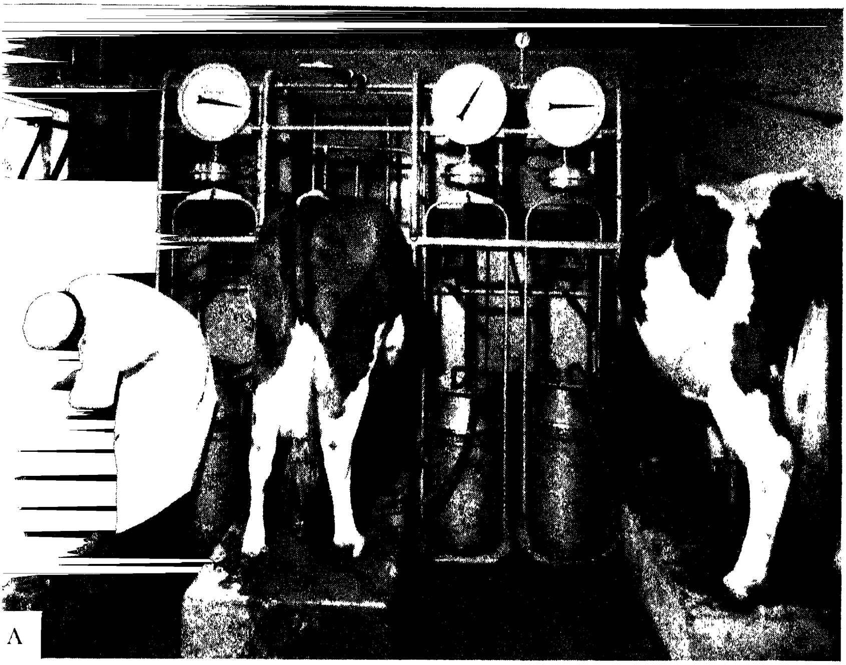


PLATE I

A Helicopter spraying Potatoes against Blight

B An automatic Auger-feeder distributing Maize Silage to Fattening Cattle



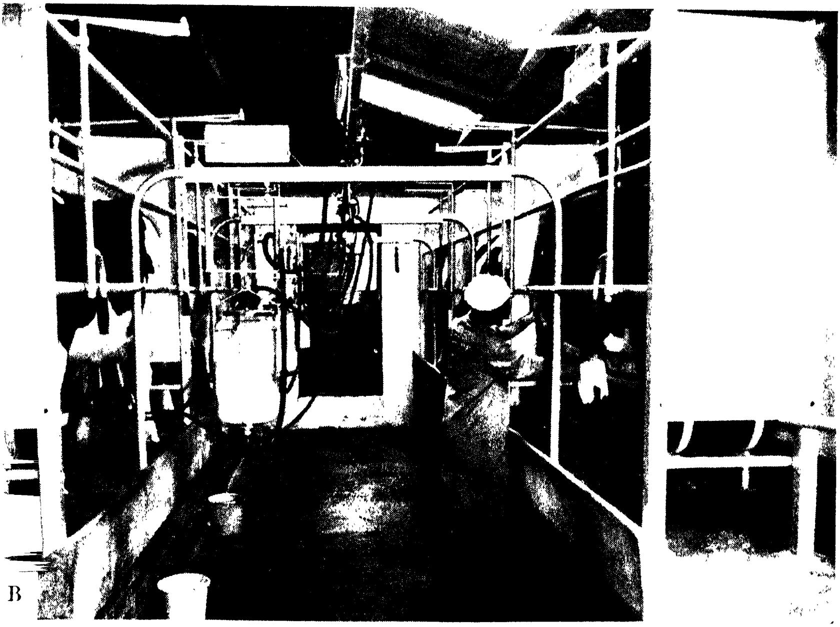


PLATE II

. Abreast two-level Parlour with one stall, one unit, direct-to-churn Milking Plant

, Tandem Milking Parlour showing the Operator's Pit laid to proper falls. The standings should have a fall of 1–1½ in. towards the channel and the passages a fall of 1 in. The whole floor should be sloped lengthwise towards an outside drain at the rate of ½ in. per cow. The channels should have no fixed covering and where they cross a passageway they should be covered with removable iron gratings or concrete slabs. The channels should run to a trapped gulley just outside the building, and it is an advantage if the gullies are fitted with strainers to intercept straw, etc. In mucking out by hand, labour can be saved if there is a ramp outside the cowhouse up which the manure can be taken in a barrow and tipped into a trailer or manure spreader. If a pit is used for the manure it should be at least 60 ft. from the cowhouse and it should have a low retaining wall and a concrete floor. In some cowhouses, to save labour in mucking out, a scraper driven by a small motor is fitted in the dung channel.

Walls. The walls can be of brick, stone, concrete blocks or panels and there should be a damp-proof course. Internally the walls are rendered up to 4 ft 6 in. in cement to provide an impervious, easily cleaned surface. Walls should not be too high ; 7 ft. 6 in. to the eaves is ample.

Roofs and Lighting. Roofs can be of slate, tile or asbestos-cement but should not be of corrugated iron. Ventilation should be provided. Natural lighting should be at the rate of 4 sq. ft. of wall window for each cow or 3 sq. ft. of roof lighting. Electricity should if possible be used for artificial lighting. If filament lamps are used, 80–100 watts per cow is the usual allowance, or one-third of this rate for fluorescent lighting. The lighting is most effective if provided at eaves level behind the cow.

Doors. For single range cowhouses the doors used by the cows should be 4 ft. wide and 6 ft. high, in the clear. For double range cowhouses the doors should be at least 8 ft. wide in the clear ; they can be double-hung or it is an advantage to have sliding doors although they are inclined to be draughty. Where possible, sliding doors should be hung internally to protect the sliding gear, but if hung externally the sliding gear should be protected by a hood.

It will be seen from the dimensions given above that the internal width of a single range cowhouse without a feeding passage is 14–15 ft. and a double range cowhouse 26–27 ft. or 32–35 ft. if there are feeding passages.

The Dairy. Milking in a cowhouse is normally by either a bucket or an in-churn milking plant. The milk has to be taken by hand or on a trolley to the dairy for cooling, though in large cowhouses overhead runways are sometimes used. To avoid unnecessary walking the dairy should be placed as close as possible to the cowhouse. With small cowhouses, for up to say 16 cows, the best position for the dairy is at one end : but for larger cowhouses it is better to have the dairy at the centre of one side. Other considerations affecting the siting of the dairy in relation to the cowhouse are that it should be in the coolest possible position, that is, on the north side. The Regulations also prohibit direct access from the cowhouse to the dairy ; there has to be either a small ventilated lobby between them or the dairy has to be approached from outside the cowhouse, often under a short covered way. For easy working the food store should be placed in much the same position as the dairy, that is at one end in the smaller cowshed and either centrally or at one end in large sheds.

The Yard and Parlour System. There are several variations in the yard and parlour or milking house system. In its simplest form the cows graze out of doors all the year round and are milked in a movable shed or bail, taken from field to field with them. Sometimes the bail is kept for the winter in a sheltered spot on concrete paving to provide easier conditions for milking. The cows may also be housed for the winter in temporary or permanent yards and milked in a bail on an adjacent site. Permanent accommodation is, however, provided most frequently and comprises essentially housing for the cows, which is generally open, partly covered or covered yards or a tie-up cowhouse unsuitable for milking, an assembly area where the cows are kept while waiting to be milked, and the milking parlour itself.

The Milking Parlour. A milking parlour is a highly specialised building used only for milking, a skilled operation which takes up about 40 per cent of the time of looking after a dairy herd. It is essential, therefore, for the building to be as labour saving as possible ; it should also be easy to keep clean, arranged so that the cows can be got in and out quickly and the cowman can do his work efficiently and with the least amount of effort. There are many designs of parlour and the most suitable for a particular farm will depend on such factors as the number of cows, their average yield, the milking routine to be used, the labour and time available for milking, whether concentrates are to be fed in the parlour, the amount which can be spent on the parlour and its equipment and the size and shape of the site or building available for the parlour. The milking equipment is also important. New developments in machines and in the technique of milking are continually occurring and this affects the design of parlours. There are three main types of milking machine. In a bucket plant the milk flows to a bucket which has then to be carried to a cooler. This is probably the simplest and cheapest form of machine. With an in-churn plant the milk goes direct into a churn in which it is also cooled and dispatched from the farm : the churns are taken from the parlour on a trolley or overhead runway. The in-churn plant saves labour by handling the milk in bulk and in the same vessel. The third is the releaser type of plant in which the milk from the milking unit is carried by a common pipe to the dairy where it passes under vacuum over an enclosed cooler into churns or into a bulk tank. This is the most expensive plant but the most labour saving in the actual milking though cleaning is more difficult and slower than the simpler and cheaper chemical treatment generally sufficient for bucket and in-churn plants.

Choice of Parlour. There are basically two types of milking parlour, those with two milking stalls to each milking unit and those with one stall to each unit. With two stalls per unit a throughput of 10 cows per unit per hour is usual but with one stall per unit 8 cows per unit can be milked in an hour. The greater throughput of the two stall to one unit type is because one cow is being fed and prepared for milking while the other cow of the pair is being milked. As a result the unit is more fully used and the cow has longer to feed in the parlour. The advantage of feeding concentrates in the parlour is that it avoids the need to have expensive yokes and mangers for individual feeding in a yard. A cow will only eat about $\frac{3}{4}$ lb. of food per minute in a parlour and it will require some minutes longer than it requires for milking to get through a reasonable quantity of concentrates.

With one stall to one unit a more regular routine is possible with each cow and this encourages a quicker release of milk : for herds with high yielding or slow milking cows one unit to each stall is to be preferred if the concentrates can be fed elsewhere.

The layout of the stalls in a parlour can either be *abreast* where the cows stand side by side, or *tandem* where the cows stand head to tail. The same type of milking machine can be used in both and there is little to choose between them in the speed at which cows can be milked. The tandem parlour usually requires a smaller building and there is no stooping, so the work is much less tiring ; on the other hand a building for a tandem can be more expensive to construct.

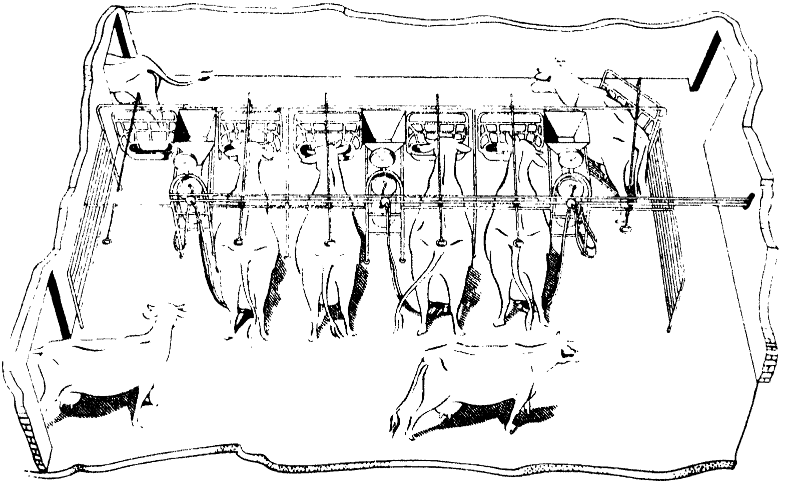


FIG. 5.—ABREAST-TYPE MILKING PARLOUR.

The Abreast Parlour. The abreast parlour can merely be some stalls separated from the rest of a cowhouse, to which the cows come only to be milked, entering and leaving by the same door. This is not the most labour saving arrangement and it is usual to have a special building with 2–8 tubular steel stalls arranged in pairs. The layout of a typical abreast parlour is shown in Fig. 5 and Plate IIA. It will be seen that a length of 16 ft. 6 in.–17 ft. 6 in. is required, and a width of 15 ft. 6 in. for four stalls. To reduce the amount of stooping, stalls are sometimes raised 14–16 in. above the level of the rest of the floor. Cows can step up this height but for anything higher an intervening step is required, which can be an obstruction.

The Tandem Parlour. In this type of parlour the cowman works in a pit 30–36 in. below the stalls. The pit can either be sunk below ground level or the stalls can be built up. A tandem parlour can be arranged with the stalls in the form of an L or U, or in one row on one side of the pit, or two rows on either side of the pit. The cows enter separately from a common passageway 3 ft. wide. Details are shown in Fig. 6. There are two simplified forms of tandem parlour without access passages, in which the cows are brought in and out in batches and there is one milking unit to each pair of cows on either side of the cowman's pit. In the *chute* parlour the cows enter in pairs up steps or a ramp either side of a narrow pit, and the stalls are placed one in front of the other without separate passages so that both the cows on one side have to enter and leave together. By omitting passages a narrow building 10 ft. 3 in. wide and 16–20 ft. long is large enough for four stalls, and this is probably the cheapest and simplest form of tandem parlour for a herd of medium size. In the *herring-bone* parlour the layout is the same but there are no separate stalls : two tubular rails on either side of the pit hold batches of 6–10 cows in echelon. A very high rate of operation is possible because the milking routine has to be kept very short if the cowman is to manage 6–8 units ; little individual attention to the cows is possible (Fig. 7).

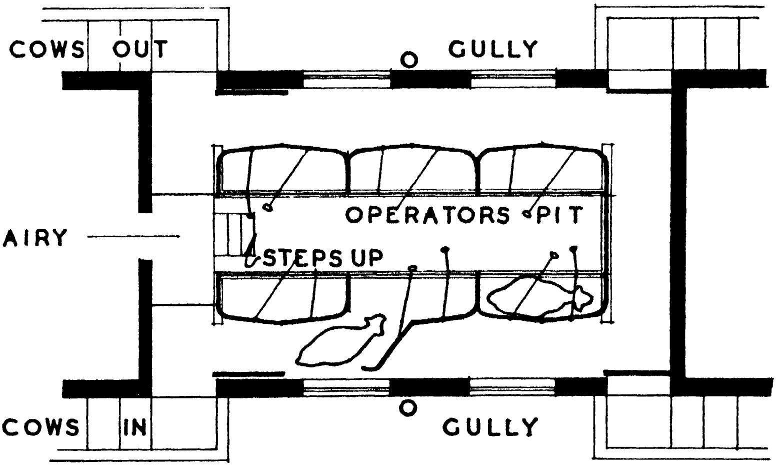


Fig. 6.—Tandem-Type Milking Parlour.

The principal points in the construction of a parlour are as follows :

Floors. Concrete is the only suitable material. For drainage, the floors should have a fall of 1 in 40 towards shallow, open, dished channels leading to outside gullies, the channels being placed at the rear of the parlour in the abreast type and along the side walls in the tandem type.

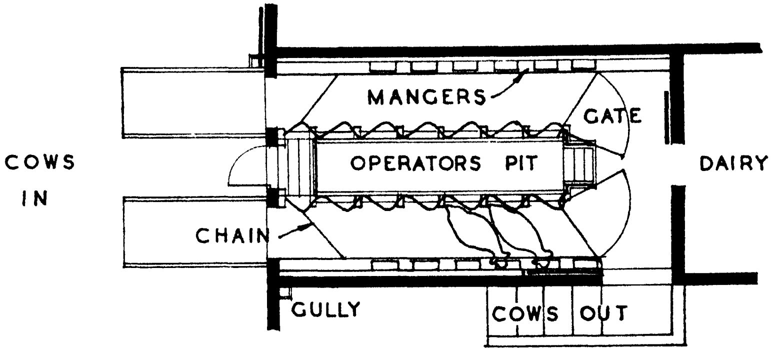


FIG. 7.—HERRING-BONE MILKING PARLOUR.

Walls. Brickwork, concrete or stone should be used and finished with a smooth washable surface for the lower 4½ ft. Waterproof paint, or even glazed tiles, are an improvement but add to the cost.

Cowman's Pit. In a tandem parlour it is usually simplest to excavate for the pit but where site conditions are unsuitable the milking stalls can be raised. Cows enter and leave raised stalls either by steps which should be broad and each not more than 10 in. high or by a ramp with a slope of up to 1 in 3 ; ramps, however, may get slippery. The wall of the pit alongside the cows should slope to allow room for the cowman's feet and should be surmounted by a kerb.

Stalls. Tubular steel is used. In an abreast parlour stalls are 5 ft. 6 in. long and each pair is 7 ft. or 8 ft. 6 in. wide depending on whether bucket or in-churn plant is used. Tandem stalls are usually 7 ft. 6 in. or 8 ft. long and 2 ft. 6 in. at the widest point with gates at each end.

Lighting and Ventilation. Natural and artificial lighting are most effective if provided overhead. Ventilation should also be arranged through the roof.

Doors. A width of 3 ft. 3 in. to 3 ft. 6 in. in the clear is usual. To save walking it should be possible to open and close entry and exit doors to the parlour as well as doors to the stalls by lever or cable from the washing area or cowman's pit.

Services. Water, hot and cold, should be laid on ; in a tandem parlour it is worth while laying on water to each stall.

Feeding. Feeding in the parlour can be highly mechanised. Mangers can be fitted in all types of parlour either to the stalls or to the parlour itself, depending on the type. Mangers may be filled from small overhead hoppers which in turn are supplied mechanically from an auger above them leading from a food store or by gravity through tubes from an overhead bulk tank. A loft over the parlour makes the bulk storage easier to arrange. The hoppers supplying mangers can be fitted with metering arrangements to regulate the amount of food let into the manger.

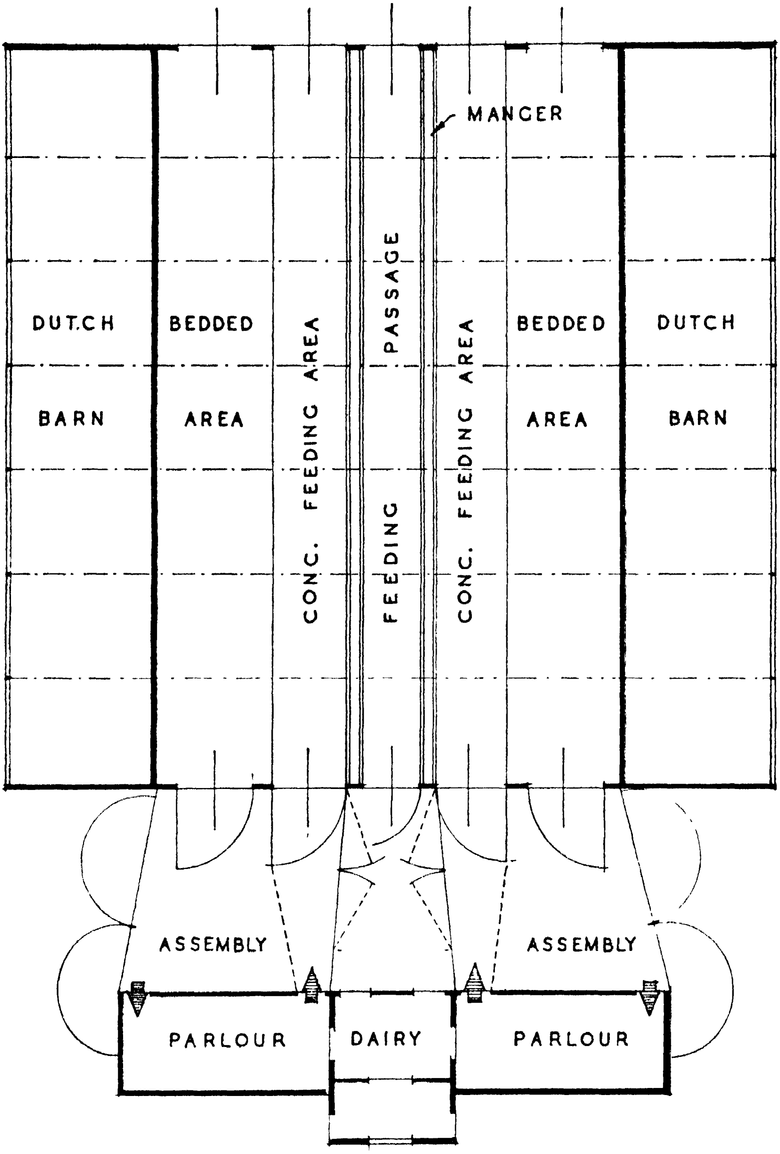


FIG. 8.—YARDS AND MILKING PARLOURS (C. L. A. McTurk Design No. 1).

Assembly or Collecting Yards. An essential part of the parlour system are assembly yards, where the cows are collected before and after milking (Fig. 8). An uncovered space of 20 sq. ft. per cow is sufficient and it can conveniently form part of the concrete paving around the milking parlour or even part of the yards in which the cows are housed provided it can be separated by gates or a chain at milking times. A funnelled approach from the yard to the entry door of the parlour prevents too many cows trying to get in together. An " electric dog " also helps to get cows into the parlour : it consists of an electric fence wire stretched between two parallel side wires in the assembly yard. As the cows go through the parlour the wire is drawn up behind those left in the yard by means of a cord in the parlour. On leaving the parlour the cows can return direct to the yards in which they are housed or they can be retained in a dispersal yard until they can be driven back to other yards or the fields.

The Dairy. To reduce the distance which milk has to be carried, either by hand or mechanically, the dairy should be situated as close as possible to the cowhouse or milking parlour. While a milking parlour can, and should, open directly into the dairy, the Regulations, as explained earlier, do not allow this with a cowhouse. A dairy also has to be kept cool so that a site on the shady side of other buildings, normally the north, is required. At the same time a hard approach road and turning room should be provided for lorry or other transport taking the milk away.

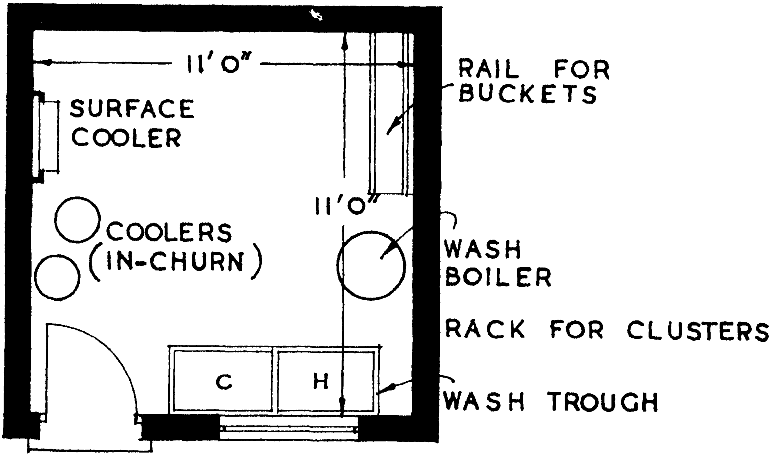


Fig. 9.—Dairy for a Small Herd.

A dairy is usually a single room in which the milk is cooled and stored temporarily and in which the milking equipment is washed and kept. Cleanliness is, therefore, highly important both in the approaches to the dairy and in the building itself. The size of the dairy will depend on the amount and size of the equipment to be housed. This may be :

(*a*) A cooler, most often a surface cooler, hung from the wall or a stand. With in-churn milking there is a special cooler placed on the churn and water flows over the outside of the churn into a tray. Where there is insufficient water (3 to 4 gallons per gallon of milk to be cooled) or it is too warm in the summer, some form of refrigeration may be necessary involving additional plant and possibly a chilled water storage tank or a tank in which churns may be immersed.

(*b*) An electric water heater or a boiler to provide hot water for washing.
(*c*) A steam raiser and sterilising chest where steam sterilisation is practised.
(*d*) Hot and cold water wash trough.
(*e*) A hand wash basin, if not provided elsewhere.
(*f*) Racks for clean equipment.
(*g*) The milking machine power unit, if small and electrically driven.

Where electricity is not available, water will have to be heated by solid fuel : a separate boiler room and fuel store are then necessary and space outside the dairy will also have to be provided for the milking machine power unit. A dairy should not be unnecessarily large, and where milk is not retailed a room of 100 sq. ft. is sufficient for a small herd, 150 sq. ft. for herds of about 30 cows and 200 sq. ft. for larger herds. Fig. 9 illustrates an all-electric dairy for 30 cows.

To provide clean conditions in the dairy the walls should be cement rendered and if possible finished with a waterproof paint ; white glazed tiling is better still, though expensive. A flat ceiling of asbestos-cement sheets is desirable as it is easily washable, but ventilation outlets through it will be needed. A well-made concrete floor is best, reinforced with steel chequer plating where there is most wear from churns, although blue bricks well pointed in cement mortar can be satisfactory. The floor should have a slope for drainage to open channels leading through a hole in the wall to an outside gulley. Good natural lighting by windows in the wall and overhead artificial lighting are also important. The labour of handling churns can be much reduced by using overhead hoists and rollers inside the dairy and outside by a platform for loading on to lorries 3 ft.- 3 ft. 6 in. high, approached by steps or a ramp.

Bulk Collection. A recent development affecting dairy design is the introduction of bulk collection of milk in a tanker lorry calling once a day or every two days. The milk is stored and cooled in a stainless steel tank suspended in a water bath and surrounded by an insulating jacket with an outer case of stainless steel or resin bonded fibre glass. The tanks are large—the smallest size now in common use is 125 gallons requiring about 30 sq. ft. of floor space with an extra 2 ft. around it for cleaning—so that there should be adequate room in the dairy and an opening wide enough to get the tank installed. The tanks are also heavy so that the floor should be well constructed. Tanks are being developed in which the refrigerating unit and water bath are separate from the milk vessel so that they can be more easily fitted into existing buildings. A good access road right up to the dairy is required for the heavy tanker collecting the milk (Fig. 10).

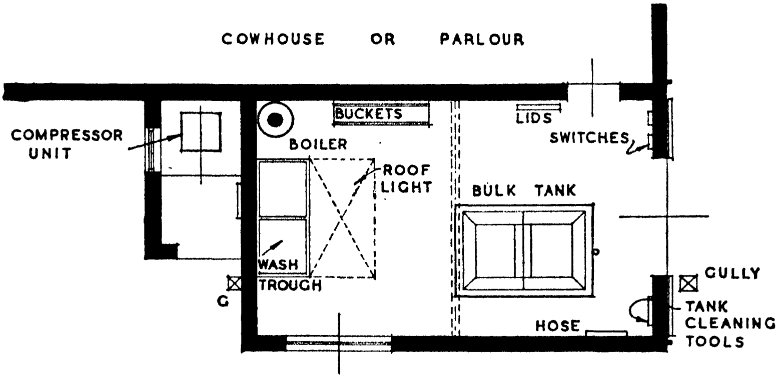


FIG. 10.—DAIRY WITH BULK MILK TANK.

YARDS FOR CATTLE AND OTHER LIVESTOCK

Because of their adaptability yards are becoming more and more popular for housing all forms of livestock but a good deal of care needs to be taken over their design and layout if some of the advantages are not to be lost by poor design, especially when improving or adapting existing buildings. The saving of labour and the comfort of the stock are the most important points to be considered. So far as labour is concerned the main problem is one of movement, partly of large quantities of bulky materials such as hay, roots, silage and other fodder being taken in and manure coming out, and partly of animals, particularly dairy cows, going in and out. It will obviously help if the distance over which the materials have to be carried is kept as short as possible by having storage for the fodder and the yards close together or even incorporated in the same building. Some of the carrying can even be eliminated if self-feeding of the silage can be arranged. Mechanical appliances will reduce the labour required —a tractor and trailer or a trolley for filling mangers and loaders, bulldozers and other implements for removing the dung. Buildings need to be suitable for the use of machinery. Mangers should be along the outside of the yard so that they can be filled without entering the yard, and wide spacing of gates and stanchions will enable tractors and machinery to get in for cleaning. For the comfort of the animals, generally cattle, the important points are freedom from draughts, shelter from bad weather, dry lying space and an adequate length of manger.

Yards can be covered or partly covered. With partly covered yards orientation is important and the open side should face south-east and away from the rainy quarter ; more shelter is given if other buildings, particularly a tall building like a dutch barn, are on the north side. To prevent draughts, at least two adjacent sides, and not opposite sides, of a yard should be enclosed with a wall, not necessarily to the eaves, or with other buildings ; and the eaves should be kept as low as possible compatible with getting tractors into the yard when full of manure.

Size and Shape. The size and shape of a yard are largely dictated by the length of manger and floor space per animal to be provided. The manger length should be 2 ft. per head for young stock and 2 ft. 3 in.–2 ft. 6 in. for adult animals. It is usual to allow 40–60 sq. ft. of space for yearlings, 80–100 sq. ft. for dehorned dairy cows and 100–120 sq. ft. for other cows and strong bullocks. With partly covered yards about one-half the space mentioned should be covered and, to prevent driving rain penetrating too much of the covered area, it should be at least 20 feet from back to front and not more than 10 ft. high at the eaves.

Mangers should be situated where there is short and easy access without sharp corners from fodder stores and along one or two sides of a yard so that they can be filled from outside. Where there are several yards a central feeding passage with mangers and yards on either side is a convenient arrangement. The passage should be wide enough for a tractor and trailer, that is about 9 ft. and in some designs it is raised with ramps at either end as this makes it easier to fill the mangers. Where the passage is between two covered yards the convenience of the shelter often justifies the extra cost of having a cover over the passage, but with partly covered yards it is usually more difficult and costly to cover the passage. The mangers will be supplied from a dutch barn which if possible should be alongside the yard and can even form one wall. Bedding will also be supplied from the barn. A food room for concentrates and roots should be near by.

Silage. If silage is fed the silo should be close to the yards or alternatively the cattle can be allowed access to the silage to feed themselves as this saves the labour of handling bulky material. For self-feeding the silo may either be in the yard or between two yards or in an adjacent dutch barn but if the layout of existing buildings does not allow this kind of arrangement or if partly covered yards are used the silo can be a short distance away, sometimes along one side of an open yard. There should be a hard approach to the silo and the area around it should be concreted. Where cattle have access to the silage all the time it is sufficient to allow 6–9 in. of the face of the silage for each adult beast either at the end or along one side of the silo. The silage should not be more than 6 ft. high and special feeding barriers or an electrified wire along the face of the silage will prevent the animals wasting it by pulling out more than they need. Where *ad lib* self-feeding is not required, labour in feeding can be saved by having a movable feeding barrier or fence adjoining the silo in front of which loose silage, hay or roots can be put for the cattle to feed themselves.

Litter. To keep the cattle reasonably clean it is important to have sufficient straw or other litter available for bedding. In a fully covered yard 15–20 lb. of straw per day should be provided for each fully grown beast, equivalent to 1½–2 tons for the winter. Where straw is in short supply a much smaller quantity is needed if the yard is divided into a bedded area for resting and a concreted feeding area. The bedded area should have an area of 50 sq. ft. per head for adult stock and should be well covered with straw as soon as the stock are put in. The manure pack which results soon heats up and keeps the animals warm. To prevent the waste of straw the bedded area should be kept free of movement, mangers and water troughs should be kept outside and access to a milking parlour should not be from the bedded area. The concrete feeding area should be at least 10 ft. wide and should be kept clear of dung and straw by the daily use of a scraper. The feeding area can either be covered or open but, if it is open, it is usually larger and includes a loafing or exercise area. The design of this and other types of yard are illustrated in Fig. 11.

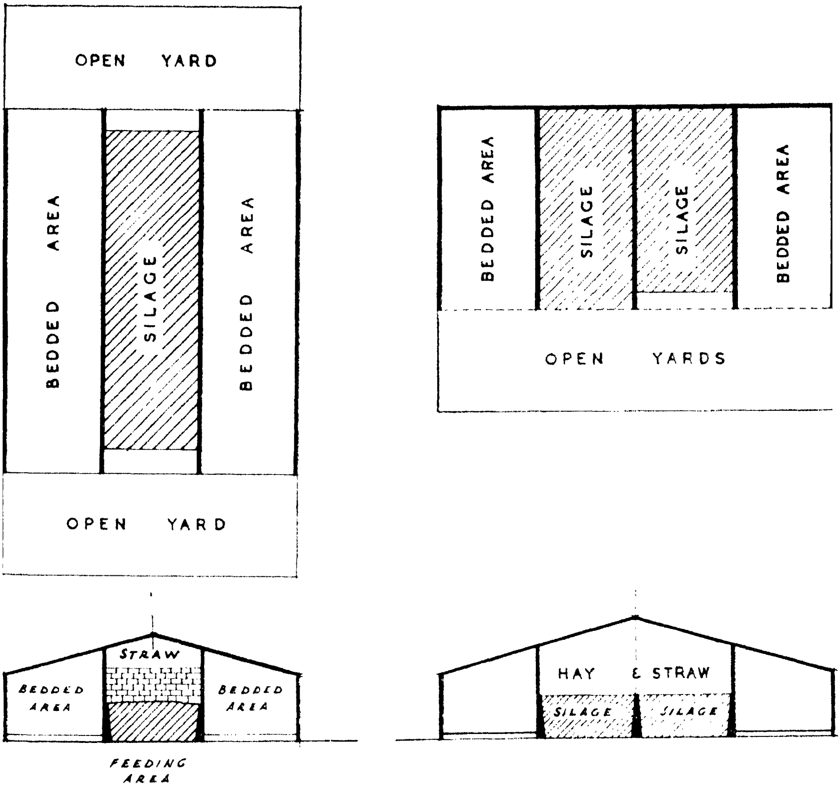


Fig. 11.—Partly Covered Yards with Fodder Storage.

Slatted Floors. An alternative way of saving straw is the use of a raised slatted floor on which the animals are kept without any bedding. They live on the slats and the dung is forced by their hooves on to the floor below from which it is periodically removed. Although a slatted floor adds to the cost of a yard, this is partly offset by the fact that less space is required, 35–45 sq. ft. per cow is sufficient and 15–20 sq. ft. for yearlings. Slats of hardwood, concrete and wire mesh have proved the most durable and the cheapest. The width of the slats varies from 2 in. with a gap of 1 in. for calves to 3–6 in. with a 2 in. gap for cows.

The use of slats is a new development, and experience has shown that the main problem in design is the removal of the dung from beneath the slats. The depth of storage to be provided for the dung below the slats depends on the system of management. Where the liquid is allowed to drain away and little hay or litter is allowed to fall through it has been found that 6 in. is sufficient for calves and 12 in. for cows for each month. If litter is allowed to fall through or the dung is handled as a sludge a greater depth is necessary. The dung can be removed in various ways : it may be swilled away with water and then handled as a sludge or it may be removed by a tractor fore-loader. If there is not much space between the slats and the floor beneath, the slats will have to be removed before a fore-loader can be used. If there is at least 6 ft. between the slats and the floor the tractor can be used underneath the slats without disturbing them. Where there are concrete slats which are heavy, it is important to provide at least this depth to avoid the need for moving them. It is also important, particularly where the slats are raised well above the floor, for the enclosing walls to be draught proof to provide reasonable comfort for the stock.

Materials. A wide range of buildings is suitable for yards but a framed structure with the stanchions spaced as widely apart as possible is the most economical and adaptable. Materials which are not affected by corrosion from moisture should be used and reinforced concrete with asbestos-cement roof covering is very suitable. The building should not have too wide a span as otherwise the height at the ridge becomes excessive, and the building may be cold and draughty. The height at the eaves should be about 10 ft. or 12 ft. if there are tie beams as this allows sufficient, but not too much head-room when the manure has risen in the yard. Walling can be of brickwork, concrete blocks or rough timber, but to reduce cost the upper part of the walls can be sheeted in asbestos-cement or corrugated iron. With open fronted yards the walls should be carried up to the eaves. Divisions between yards should be removable for cleaning out and high enough when the yard is full of manure. Timber or tubular steel rails are usual and there should be wide gates which can be raised. Around the yards the same type of rails may be used instead of walls, but solid walls may be necessary to provide shelter even in an open yard. Floors of covered yards can be of earth, stone or hardcore but for open yards concrete is very desirable to keep the yards dry, though efficient drains to dispose of the rain-water are essential.

Mangers. In the same way that removable rails round at least part of a yard make for greater flexibility of use, so do portable or removable mangers make a less rigid design and save the expense of fixed mangers. There are various types of movable and adjustable mangers in timber and in steel : they can be free standing, suspended on chains or on hooks on a rail or bolted to parts of the main structure. Where there is a fixed feeding passage part of the passage can be used as the manger on which fodder is placed, the cattle being kept from the passage by a feeding barrier. Where fixed mangers are provided they should be 2 ft. 6 in.–3 ft. wide from back to front and deep enough to provide plenty of room for bulky food. The back of the manger adjoining the feeding passage should not be more than 3 ft. high as otherwise it is more difficult to put the food in. The front adjoining the yard should be 3 ft. 6 in. above floor level to allow for the build-up of manure but 15 in. is sufficient if there is a clean concrete area in front of the mangers. Some form of barrier through which the cattle feed is required to keep them out of the mangers and to prevent bullying. Where concentrates are fed in the mangers closable yokes are usually installed so that the feeding can be controlled.

Water troughs should also be provided and fixed at the same height as the mangers ; a 6 in. length of trough for each adult beast is sufficient.

LOOSE BOXES

Loose boxes are some of the most useful general purpose buildings on a farm and there should be sufficient of them, conveniently placed. A box about 12 ft. × 14 ft. to give a floor area of 150–180 sq. ft., is suitable for general purposes. Boxes are best grouped together in ranges, facing as near south as possible: division walls between boxes need only be up to eaves level. A covered feeding passage is an advantage, though it adds to the cost. Each box should have a door leading on to an outside concrete causeway. The doors should open in two halves (half-heck) with the lower half at least 4 ft. high and protected inside with sheet metal. The internal fittings should include rings for tying stock, and a manger and water bowl or standpipe, adjustable in height if different types of stock will use the box. The floor should be of concrete, insulated and sloped to an outside drain. Roof lighting is preferable, though hopper type windows set high up can be used. Ventilation should be provided at the ridge. One or more boxes in the farmstead will be required as isolation boxes and should be sited as far away as possible from other buildings.

BULL PENS

Bulls are too often housed in unsatisfactory conditions, such as in a stall in a cowhouse or in a small dark loose box, and this aggravates their natural bad temper and makes their handling unnecessarily dangerous. A bull should have a properly constructed box with either a yard or a small, well-fenced paddock. The box should be in a sheltered spot, facing south, and where the bull can see what is going on ; it should also be close to where the herd is kept. It should be soundly constructed with a floor area of about 180 sq. ft. and a length of not less than 10 ft. There should be a manger and water bowl on one wall, arranged so that the manger can be filled from outside, either through a hatch or from a feeding passage : it is an advantage to have a catching yoke or ring fixed over the manger. The manger and water bowl should be built up from the ground in solid brickwork or concrete to prevent the bull damaging them by getting his horns underneath. Doors should also be stout and with a smooth surface, lined with sheet metal, as this makes them more difficult to damage. The doors and manger should be placed so that the bull has room to lie down out of the way of draughts, and the door between the box and the yard should be hung so that it can be operated from outside when it is required to keep the bull in the box or in the yard for cleaning out (Fig. 12).

The yard needs to be at least 20 ft. long to provide sufficient exercise, and 30 ft. is better. The floor should be of concrete roughened with a brush to prevent it becoming slippery. A bull is more contented if he can look out from the yard, but if solid walls are not provided it is important to have the gaps between the fencing rails or tubes so small that a bull cannot get his legs or head trapped. The best arrangement is to have a solid wall not less than 9 in. thick and 3 ft. 6 in. high. Above that, tubular rails are sufficient and enable the bull to see out. It is an advantage to have a service pen built in one corner of the yard. There should be a stout gate from the yard and some escape arrangement for use in emergency, either in the form of a gap in the wall 1 ft. wide or two upright steel stanchions across a corner forming a refuge until a man can climb over the wall behind.

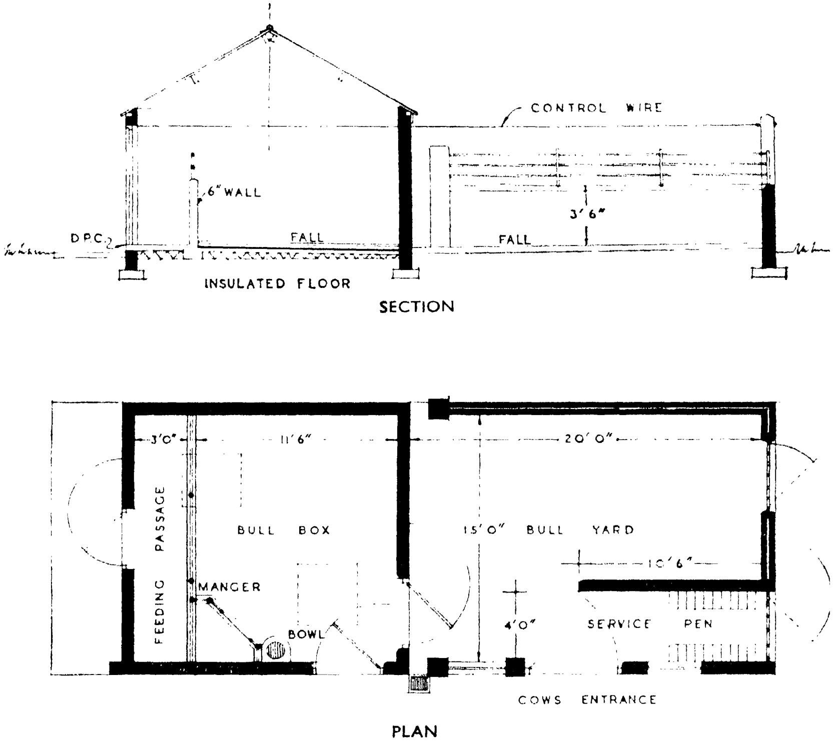


Fig. 12.—Bull Box with Open Yard.

In this plan provision has been made for two escape gaps between the bull box and the wall of the yard

CALF HOUSING

Calves, particularly for the first few months, need warm, dry housing. Concrete floors should be well insulated and have plenty of bedding ; alternatively, a false floor of timber slats or expanded metal on a timber framework is sometimes used. Doors and windows should be well fitting to prevent draughts, and the roof should be fairly low and well insulated.

Until three or four months old, calves are usually kept in single pens about 4 ft. × 6 ft. for the larger breeds and a little smaller for others. To prevent draughts solid partitions about 4 ft. high are best : they can be of rendered brickwork, concrete or sheet metal, and should have a yoke fitting for feeding and holding a bucket, adjustable in height for calves of varying ages. It is a help if some, if not all, the partitions can be removed for cleaning out and to form larger pens for housing calves in groups of 3–6 when older.

The arrangement of the pens will depend on the feeding system and the number of calves. With only a few calves a suitable loose box divided up with temporary or removable partitions will be sufficient. Where there are more calves a special unit is required situated near the dairy and mixing room, or near the nurse cows if there is to be multiple suckling. The pens should be accessible from a central passage containing shallow channels into which the pens drain : the channels discharge into gullies outside the building. Adequate lighting should be provided either by roof lights or hopper windows high up the walls and there should be outlet ventilation in the ridge. As calves sometimes die from lead poisoning from sucking or chewing paintwork, paints not containing lead or other preservatives should be used on timber or metal work in buildings where there are calves.

HOUSING FOR PIGS

Unlike other farm animals the domestic pig has almost no coat to protect it against extremes of temperature—in this country cold being the most important. The exercise which pigs get when kept out of doors is sufficient to keep them warm in cold weather but this uses up much of the energy obtained from their food. While this does not matter with breeding stock it is important on grounds of cost that fattening pigs put on weight quickly and with the minimum consumption of food. Warm indoor housing has therefore to be provided for them ; young piglets have no layer of body fat and so are very susceptible to the cold, and warm housing is even more important. Experience has shown that provided the pigs are kept warm high humidity in the air does not affect their health. High humidity causes condensation in the piggery which in time will damage the structure of the building, particularly the insulation. High humidity should therefore be avoided by good ventilation and the rapid drainage of liquids from the interior of the building. Outside runs in which the pigs dung provide a simple and effective way of reducing humidity and drainage problems.

Outdoor Systems. Where there is sufficient land available and it is dry enough to use all the year round there is a great deal to be said for running breeding pigs out of doors. They are healthier and housing problems are simpler. Gilts or in-pig sows can be kept together in temporary or permanent enclosures : they are best in groups of six or seven to the acre. Water should be provided and a shelter where the pigs can go in bad weather. A temporary building with a low roof and made of straw bales, or a timber hut, is sufficient if erected in a dry, sheltered spot. Near farrowing time some breeders consider it desirable to provide individual feeding arrangements for the sows so that each can get a proper share of food without bullying.

For sows with litters, portable arks on skids, which are moved frequently, are the most suitable. They can be put in a small fold surrounded by hurdles, or the sows may be tethered on a long chain. The ark should have a floor area of 8 ft. × 6 ft. or be rather larger if there is a creep for the young pigs. There are various designs of arks, but generally the construction is a double-skin wall coming to an apex with insulating material between. The walls can be of timber tongued and grooved boarding but, to reduce cost, sheet metal or plywood is sometimes used for one thickness of the wall. Other essentials are a stout timber floor, a draught-proof attendant's door and an entrance door placed off centre or with a baffle wall inside. It is also an advantage to provide a creep feeder for the piglets in one corner.

The main disadvantage of the outdoor system is the work involved in looking after a number of pigs in scattered units, often in bad weather during winter. To some extent this can be overcome by arranging the runs so that the housing or arks are close together, alongside a hard road, with the runs radiating out from them. A separate food hut filled once a week or so from a central store and kept near the arks will reduce the carrying of food. In winter the arks can be brought on to concrete paving, if possible where water and electricity for heating units in the arks are available.

Store and fattening pigs are sometimes kept in covered or partly covered yards in lots of about 15–30, with or without cattle. They should have sufficient straw and a separate feeding place in one corner of the yard where they can be fed apart from the cattle. If there is any risk of the pigs not being warm enough they should also have a warm sleeping place with a low roof. With more specialist enterprises, however, it is generally found that pigs fatten more quickly when kept in smaller lots and with less space to move about.

Indoor Housing. Although full scientific information about the requirements of pigs when housed indoors is lacking, experience has shown that if the pigs are to thrive the housing has to meet certain requirements. These are :

1. Roof, walls and floor properly constructed and well insulated to prevent excessive heat loss. The cubic capacity of the building should not be too large (50–80 cu. ft. per pig) so that the pigs themselves, as the only source of heat, can keep it at a reasonable temperature. A headroom of 6–7 ft. is ample and where there is a lofty roof the air space can be reduced by a ceiling at eaves level.

2. A warm dry sleeping space away from draughts. In some designs of piggery the roof over the sleeping quarters is kept as low as 3–4 ft. to form a warm " kennel " for the pigs ; an alternative is to have

a low false ceiling over the sleeping place. Pigs are naturally clean animals and to encourage them to dung elsewhere the area of the sleeping place should be kept small, 5–6 sq. ft. per pig being sufficient.

3. A separate place for dunging which may either be an outside run or a passage placed next to the outside wall. The passage should be 4 ft. wide so that there is enough room for the pigs, but 3 sq. ft. per pig is sufficient floor space.

4. Sufficient trough space for each pig to feed without overcrowding and bullying. This is one of the most important factors in the design of pens as it controls their size and shape. A length of 1 ft. of trough for each fattening pig and 1 ft. 6 in. for sows and boars is usual ; the trough should be lined with 12 in. wide, half-round, salt-glazed channels.

5. Draught-proof partitions between pens, at least 3 ft. 6 in. high and sometimes carried up to the roof. Partitions can be of 4½ in. brickwork or concrete blocks. The pen front adjoining the feeding passage can either be solid (fixed or swinging) or open, consisting of rails of galvanised steel tubing. The bottom tube is often a water pipe, either with holes at intervals through which the water flows into the troughs below, or supplying automatic water bowls.

6. Impervious but insulated floors sloped so that drainage runs quickly from the pigs to the outside to prevent excessive humidity. A fall of 1 in. in 3 ft. is usual. To save labour, dung can be removed from the enclosed type of piggery as a sludge either by the use of automatic scrapers or by having a slatted floor in the dunging passage leading to a storage tank outside the building or to a dung cart.

7. Adequate but not excessive inlet and outlet ventilation as described in the earlier section on ventilation. Forced ventilation by fans is used in some piggeries. In one design fans draw the air at each end into a central overhead duct from which it passes over the pens before reaching the outlet. In others extractor fans are placed in the outlets.

Several designs of piggery meet these requirements with varying efficiency. They can broadly be divided into two types, first, those with outside runs and second, totally enclosed houses.

Piggeries with Outside Runs. There are two designs of piggery with outside runs for dunging. The first is the *McGuckian*, in which the pens are in pairs with feeding troughs arranged along narrow side feeding passages leading off a main passage from which they are separated by a draught-proof door. The pens are long (15–20 ft.) and narrow with all walls carried up to the roof. There is a small doorway with a baffle leading to the outside run and the roof of the pen is carried down over part of the run to form a verandah.

The *Harper Adams* house (Fig. 13) is a single range building sometimes constructed as a lean-to off an existing wall, with a single feeding passage on to which the pens and feeding troughs face. The pens are normally 11 ft. long and 8 ft. deep. The roof is low, being 3 ft. 3 in. at the eaves and 6–7 ft. over the feeding passage. The outside run is approached by a small doorway with an outside baffle wall which has a roof over. The pen walls are carried up to the ceiling and the feeding passage acts as a horizontal ventilating shaft, regulated by the entrance doors at each end which open in two halves. Six to ten pens form a suitable length of building, otherwise the range becomes too long.

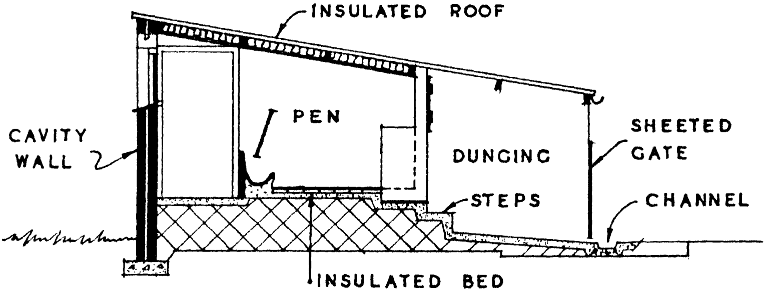


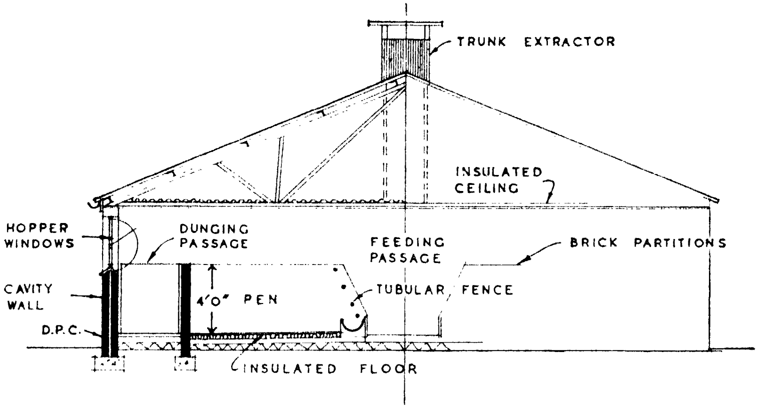
FIG. 13.—HARPER ADAMS-TYPE PIGGERY.

With both these types of house it is important that the runs should face south and have wide gates so that they can be cleaned out by a tractor with a fore-end loader. If plenty of straw is used the yards need only be cleaned out at long intervals. The food room can be placed at one end or in the centre.

Totally Enclosed Piggeries. The best known is the *Scandinavian* or *Danish* type (Fig. 14A), which at times has had a poor reputation because it has been incorrectly copied with inadequate insulation. It comprises two ranges of pens along either side of a central feeding passage, and dunging passages along each outside wall. The pens are 10–12 ft. in length along the feeding passage and 8–10 ft. wide, separated by a partition from the dunging passage which is about 4 ft. wide. To conserve heat a flat insulated ceiling over the whole building at eaves level is an improvement; a cheaper alternative is a false ceiling only over part of the pens. There are several variations of this type of house. In one, the divisions separating the dunging passages from the pens are carried up to the roof, and the passages have separate and higher roofs so that a tractor with a scraper blade or loader can be used to clean them out. In another, the pens are placed against the outside walls where the headroom is kept low and the dunging area is next to the feeding troughs and central passage.

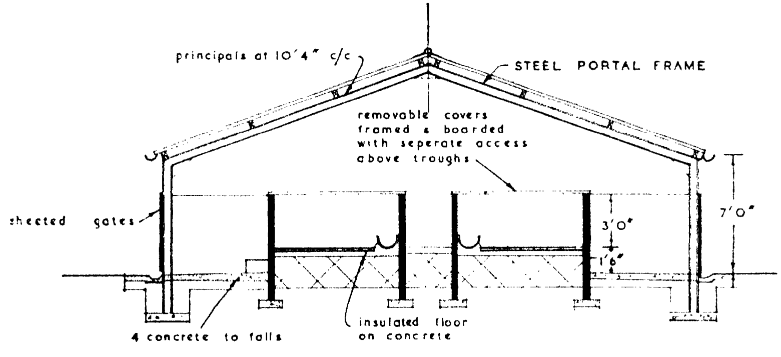
For farms with plenty of straw there are designs of piggery with the pens covered in deep straw in which the pigs keep themselves warm without the need for so much insulation and ventilation as in other types of house. The pens are arranged on either side of a central passage and are separated by partitions which can be removed for cleaning out periodically. There is no dunging passage but the floors of the pens are at a lower level towards the outer wall to contain the straw.

The *Solari* piggery (Fig. 14B) is another design adaptable to other uses. It comprises a steel dutch barn with double pens arranged on either side of a central feeding passage. The pens are divided by 4½ in. brick walls 3–4 ft. high : the inner sleeping pens have hinged timber boarded covers which can be raised or lowered according to the temperature in the pens. The outer dunging pens are 12–18 in. lower and are deeply strawed. They can be cleaned by a front-end loader through large doors.



SECTION

Fig. 14.—A. Scandinavian-Type Piggery.


principals at 10'4" c/c
STEEL PORTAL FRAME
removable covers framed & boarded with seperate access above troughs
sheeted gates
3'0"
1'6"
7'0"
4 concrete to falls
insulated floor on concrete

CROSS SECTION

Fig. 14.—B. Solari-Type Piggery.

Farrowing Pens. Accommodation for indoor farrowing can be arranged in loose boxes, in small pens provided in a fattening house or for larger units there may be a special farrowing house. Requirements are the same as for other houses except that warmth is even more important since young pigs require a higher temperature and a sow and litter give off less heat. Other points are a floor area of 60–90 sq. ft. with separate dunging place or small outside yard ; farrowing rails round the pen to prevent the sow crushing the piglets and a creep to which the piglets but not the sow can go for feeding. Artificial heating reduces losses of young pigs. It can be either an infra-red radiant heater hung over the creep or electric heating wires incorporated in part of the floor.

Farrowing crates are sometimes used in the pens for the first few weeks as they make the sow easier to handle and protect the piglets. The crates are either in the form of a long narrow box with slatted sides to contain the sow, or they form a circular (Ruakara) structure with a central safety zone for the piglets.

ACCOMMODATION FOR SHEEP

In the past sheep have had little in the way of fixed equipment, but to make flock management easier and less laborious for the shepherd the recent trend has been to provide more.

The accommodation for lambing depends a great deal on local circumstances. The essentials are a shelter from the worst of the weather and a place where the ewes can be gathered reasonably close together to make supervision easier. A temporary shelter yard of hurdles covered with straw, or of straw bales, with a pen or two for lambing, may be sufficient ; when lambing has finished the yard can be destroyed, so simplifying the control of disease. More permanent accommodation on hill farms can be in the form of small walled enclosures or on lowland farms, in lambing sheds and yards at the farmstead. When permanent accommodation is used it needs to be well disinfected after lambing.

The dipping of sheep is an important item in good management, and in many counties it is still compulsory. Coupled with the dip should be drafting pens and a footbath. A well-designed layout can make the handling of a flock more economical of labour and more efficient. Convenient siting is important, namely a central position with good access. An adequate supply of water should be near by and somewhere to dispose of liquid from the dip without causing pollution. A common arrangement is to have a collecting pen where the sheep are gathered. From this they pass through a sorting race either to a catching pen leading to a dipping bath or to drafting pens. A short swim bath is the most popular ; it should have a capacity of ½ gallon of dip for each sheep to be dipped. Baths can be bought ready made of galvanised steel from 140 gallon capacity upwards or they can be constructed on site from concrete or brickwork. Sheep are lowered into the bath tail first, usually on their backs. After passing through the bath they climb up an exit ramp into draining pens. For large flocks a long swim bath or a circular ring bath may be preferred. Post and rail fencing for the pens is satisfactory with the rails of hardwood spaced not more than 6–7 in. apart to a height of 3 ft. 6 in. Pen floors should be of concrete. A convenient installation is illustrated in Fig. 15.

A shearing shed may also be provided adjoining the pens. This can merely be a roofed area to shelter the workers, or it can be an enclosed building in which the wool is stored as well. An electricity supply makes the use of electric shearing machines possible.

The wintering of hill lambs in buildings (as an alternative to sending them to lowland farms) is an old-established practice which has recently been extended to lambs and ewes on lowland farms. On hill farms there may be a special wintering shed, for which an existing building may be adapted, with a slatted floor ; 4–6 sq. ft. of floor area per head is sufficient, depending on the breed. A shallow pit is needed under the slats which should be of hardwood 1½ in. square with tapered sides about ⅝ in. apart and supported on timber joists. The building should be well ventilated and not totally enclosed so that the sheep do not become too pampered as this can lead to management troubles in spring when they are let out. On lowland farms more improvised arrangements can be made with existing buildings such as dutch barns and cattle yards into which slatted floors are temporarily fixed, though straw can be used as an alternative.

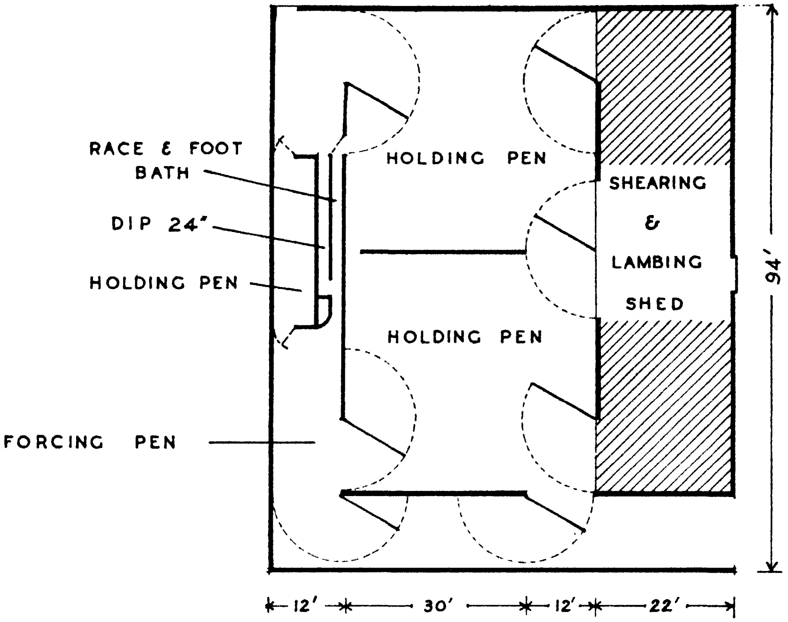


Fig. 15.—Sheep Dip and Pens.

ACCOMMODATION FOR POULTRY

Conditions in the poultry house vary from the strictly controlled environment for broiler production to the simple pole shed for growing turkeys. In an era of intensive methods of poultry husbandry, with stock housed at great density and growth rate accelerated by improved breeding methods and nutrition, our basic knowledge of the optimum environment for the different classes of poultry is rather deficient. Modern poultry houses are in consequence designed very much on a trial and error basis. If more were known of the physiological processes involved, then the needs of the chicken or laying hen for warmth, ventilation and light could be better safeguarded in the design of modern poultry houses.

Poultry are adaptable creatures and can thrive under a wide range of conditions but with less latitude in the chick stage than for the well feathered growing or laying stock. Critical temperatures, below which food is diverted from production to maintain animal heat, are especially important because costly foods are used by poultry. In practice the optimum temperature ranges appear to be: a brooder temperature of 90–95° F. for the day-old chick; 60–65° F. for the broiler reared chicken; and 50–55° F. for the laying hen.

Ventilation rates based on the replacement of 1–2 cu. ft. of air per minute per 1 lb. body weight appear optimal. The technique of controlled lighting for growing and laying stock, together with more exacting regulation of heat and ventilation, has led to the production of windowless or " controlled environment " houses, incorporating automatic heating and ventilation systems.

ACCOMMODATION FOR IMPLEMENTS

Most modern implements are expensive and when not in use need protection from damage and deterioration caused by the weather. Near-by workshop accommodation where they can be easily adjusted and maintained is very desirable.

Implement accommodation need not be close to other buildings though it is usually more convenient to have it in the farmstead. The main requirement is good road access and a site where the buildings can face north, away from driving rain and the sun. It is difficult to prescribe the amount of storage space which should be provided on a farm as the number and size of implements vary widely from farm to farm : the following are typical figures of accommodation requirements for farms over 100 acres obtained from a survey by Cambridge University:

Type	Sq. ft. of Accom.	No. of Bays of 330 sq. ft.
Rearing, grass, sheep and large arable farms . .	500–1,000	2
Dairying, mixed and heavy arable	700–1,800	4
Intensive arable and market gardens	1,000–2,800	6

For a small farm with a limited number of implements a shed with an open front is probably the most satisfactory. One or two bays can be enclosed with doors to house tractors and a workshop. The shed should be at least 20 ft. deep—22–28 ft. is better—to give full protection from the weather, and in bays 15 ft. wide. A height of 8 ft. to the eaves is enough for most implements. For small implements such as ploughs, harrows and cultivators, a simple lean-to building 10–12 ft. deep and with 5–6 ft. of headroom is adequate.

For larger farms with more implements and a number of them with engines and many moving parts, a more expensive totally enclosed shed is probably justified. A useful building is one with bays 33 ft. deep and 15 ft. wide ; the walls can be in concrete blocks or bricks for the first 4 ft. with sheeting above. One bay with a headroom of 12 ft. at the eaves makes the housing of combines and loaders easier. Doors should be 10–12 ft. wide ; sliding doors, though more expensive, are less likely to get damaged. Good overhead lighting is important, and concrete floors make servicing easier.

Workshop. The workshop can be sited either in part of the implement shed or in a separate building. It should be fitted with well-lighted work benches, racks for spare parts and tools, and an inspection pit ; water and electric power should also be provided. Overhead lifting tackle is required in a large workshop. The size of the workshop and the amount of equipment will depend on the type and number of jobs to be undertaken. It is very important that the workshop should be warm so that the operators can work in comfort.

Fuel Storage. There should be fuel storage near the tractor sheds with good road access for the tractors and tankers, but the storage should be away from wells which may be contaminated by the seepage of fuel. For diesel fuel and vaporising oil overhead tanks of 250 gallons capacity for one tractor and 600 gallons for two to three tractors are usual sizes. The tanks should not be galvanised internally as the zinc may be dissolved by the fuel. Tanks are generally rectangular and if they are mounted 4–6 ft. high tractors can be filled by gravity. The supports can be of brick, concrete or angle iron but must be substantial since the weight of a 600-gallon tank with fuel is 2½ tons. A timber or bituminous fillet placed between the bottom of the tank and the supporting pier will prevent rusting. Tanks should be tilted backwards at least 3 in. from the filling taps to form a sludge trap with a drain cock for emptying. A licence from the local authority is needed if more than 3 gallons of petrol are to be stored, and for larger quantities underground storage is a usual requirement. This is expensive and probably not justified except on a large farm.

STORAGE BUILDINGS

Dutch Barns. A dutch barn is one of the most useful storage buildings on a farm. Although usually provided to store hay and straw it can be turned to many other uses when necessary, such as a cover for grain silos and silage pits, the storage of large implements like combine harvesters, and temporary yards for livestock. An all-steel barn with a curved roof is the most popular, but reinforced concrete barns with asbestos-cement roofs are often found. There are also designs of barns in timber covered in corrugated sheeting.

Barns are usually manufactured in standard bays of 15 ft. with widths of 24, 25, 27 and 30 ft., and a height to the eaves of 16 or 18 ft. One bay 25 ft. wide and 16 ft. high would hold about 20 tons of loose hay or 8–10 tons of loose wheat straw.

To preserve the feet of the stanchions the concrete bases in which they are set should be brought well up above ground level and sloped away from the stanchions. One or more sides of a barn can be covered in sheets to give more protection from the weather. Lean-to extensions can be added, separated if required from the main barn by concrete or brick walls. Upper floors are sometimes inserted, but expert advice should be obtained before structural additions are made which put extra load on the stanchions.

A recent development is the use of one or two bays of a barn for hay drying by blowing warm air through loose or baled hay to provide high quality hay in small quantities (see p. 341). The bay has to be enclosed with airtight walls up to a height of 14 feet and air is blown by a fan through a false floor of wire mesh. It is sometimes possible to use the fan and heating system of a grain drying installation for supplying the air for hay drying as well as for ventilating potato stores. The possibility of having a combined installation should always be considered when designing a layout for one form of crop drying.

Silos for Silage. Another way of conserving green crops is by ensiling them. While much silage is stored out in fields less wastage occurs if the silage is made in a pit or trench (which can be above or below ground level) with permanent sides, a roof and drainage. A minimum width of 15 ft. is required for consolidation by a tractor, which is helped if the sides have a slope of not less than 1 in 8 from the bottom. A finished depth of 6–8 ft. is usual. Grass silage occupies about 2 cu. yd. per ton and a ton of grass will make about $\frac{3}{4}$ ton of silage.

Walls can be of precast concrete staves or plywood panels available from manufacturers, or of timber planks with a supporting framework, of concrete blocks, of reinforced concrete or of bricks made up on the site. On free-draining soils it is an advantage if the pit or trench is excavated below ground level so that the soil and excavated material will give support to the walls. Otherwise care should be taken to have the walls strong enough to resist the pressure on them when the silage is being consolidated. There should be a row of land drainage tiles along either side of the floor leading to a suitable drainage outlet. The best form of roof is a dutch barn, but if something cheaper is required a low roof just above the silage and removable in sections can be used. Corrugated steel sheeting fixed to the silo walls or to a timber framework is satisfactory (Fig. 16).

The use of tower silos for silage, a common practice in the U.S.A., is now being re-introduced into this country. Chopped silage is

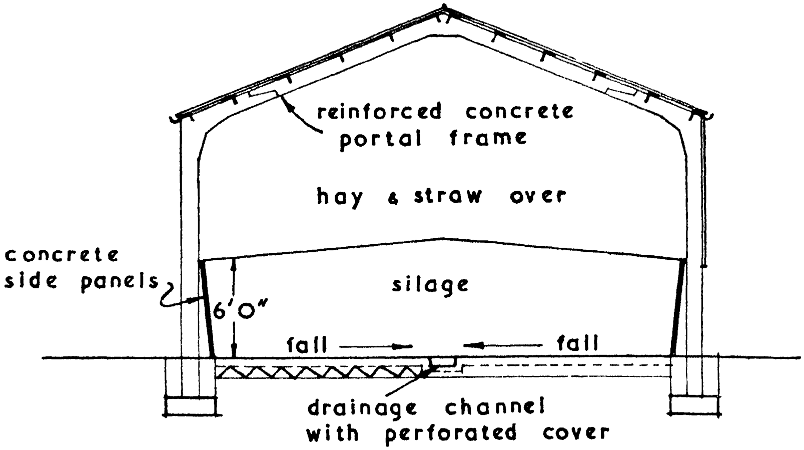

reinforced concrete portal frame
hay & straw over
concrete side panels
silage
6′0″
fall
fall
drainage channel with perforated cover

FIG. 16.—COVERED SILO WITH PORTAL FRAME ROOF.

blown into the top of the tower. It is removed for feeding by a mechanical cutter in the top of the tower, down a conveyor to the ground where it is passed by means of an auger to cattle in yards. Concentrates can be added to the silage as it passes through the auger. Large numbers of cattle can be fed mechanically by an installation of this type.

Potato Stores. The indoor storage of potatoes has many advantages over a clamp in the fields. Existing buildings can generally be made suitable for shallow storage up to 8 ft. high at no great expense ; for greater depths forced ventilation may be required and loading may be more difficult.

The main points about a building for potato storage are that it should be big enough for handling the potatoes—a width of about 20 ft. is usually considered necessary with 3 ft. of headroom when ful —and it should have wide lofty doors, preferably hinged to avoid draughts. There should also be a space of about 15 ft. in front of the potato stack when full for sorting and loading the potatoes. Walls should be strong enough to resist the pressure of the potatoes, which is about 10 lb. per sq. ft. per foot of depth, or should be strengthened, and be thick enough to keep out frost. Where there is any doubt about the insulating value of the walls they should be lined with a single layer of straw bales stacked closely together, or with loose straw tightly packed behind wire netting, or some commercial insulating materials should be used. If the storage is to be in a building with open sides such as a dutch barn, walls of at least two layers of straw bales suitably supported should be provided. Potatoes in a store should be well covered in straw, particularly if there is no roof insulation.

A ton of potatoes will occupy about 56 cu. ft., so that with shallow storage just under a square yard of floor space is required for each ton of potatoes.

Granaries. The granary is the principal building on the farm used for storing and processing food for livestock ; on larger farms the labour of constant journeys to the granary can be saved by having subsidiary food stores attached to the larger livestock buildings such as the cowhouse, piggery and poultry buildings, filled up periodically from the central granary. As large quantities of heavy and bulky foodstuffs are brought to the granary, stored and processed and taken away, a convenient central site and machinery for handling the food will reduce the work. The site should have a good hard approach for lorries and farm transport delivering and taking the feeding-stuffs away. The loading of sacks can be made easier if part of the granary floor is at lorry level, about 3 ft. 6 in., approached by a ramp so that a sack barrow can be used for moving the sacks without the need for lifting them. Where home-grown grain harvested by combine is used, it is convenient to have the granary close to the grain store or even amalgamated with it.

A weatherproof building is essential for a granary and the ground floor particularly should be dry. A concrete floor with a damp-proof membrane is best. Upper floors should be designed to take the necessary weights and can be of timber or pre-cast concrete units. It is convenient sometimes to have root storage attached to the granary and the root cutter and cleaner can be driven from the same shafting. A building with wide entrance doors and stout walls is required, and it is usual to allow 65–70 cu. ft. per ton of roots to be stored.

Grain and meal are usually stored in bins which can have sides of concrete blocks, brickwork, timber boards, plywood, galvanised metal sheets or asbestos-cement. The front of the bins should not be more than 3 ft. high so that sacks can be tipped without much effort. If the front is made of removable boards sliding in slots the bins are easier to clean out. The number and size of the bins will depend on the requirements of the individual farm, and the following figures show the space required per ton for different grain:

STORAGE SPACE FOR GRAIN AND MEAL

	Whole grain	Meal
Wheat . . .	45 cu. ft. per ton	76 cu. ft. per ton
Barley . . .	50 ,, ,,	70 ,, ,,
Oats	70–80 ,, ,,	142 ,, ,,

The bins can be on a ground floor, but handling is sometimes easier to arrange if they are on an upper floor above the processing machinery into which the grain or meal can fall by gravity. The ground floor is then free for the machinery and the storage of cake, etc., in sacks.

EQUIPMENT FOR GRAIN DRYING AND STORAGE

The general use of combine harvesters in Britain has resulted in a high proportion of the wheat and barley being threshed during August and September, and has now made it essential for most farmers to be able to store a proportion of their combined grain. A seasonal rise from August to June in the average price of wheat helps to repay the cost of drying and storing this crop. Moreover, modern marketing conditions make it advantageous for farmers to be able to hold other crops if necessary. Fortunately, research and development work have provided many satisfactory solutions of the farm grain storage problem, though some of them are high in capital cost, and some unattractive to tenant farmers. In the following pages the main systems of farm drying and storage are briefly discussed and compared.

Variations in Need for Drying. The proportion of grain that needs drying, and the amount of moisture that needs to be removed to ensure safe storage, varies considerably from farm to farm and from season to season. There are some farmers in favoured parts of the country who have never had a drier and who are quite sure that the only insurance they need is adequate combine harvester strength in relation to the amount of corn to be handled. For most farmers, however, having a spare combine harvester is neither the cheapest nor the most reliable insurance against unfavourable harvest weather, and it is necessary to have available, either on the farm or elsewhere, some means of getting at least a proportion of the grain dried. Grain harvested at 20 per cent moisture content or above will readily heat, and no practicable amount of turning can be relied on to keep it good if it is put into a bin. If a good drying wind blows through it while it is well exposed in hessian bags, it will rapidly lose some of the moisture ; but this is a form of drying that is too unreliable to be advocated. Grain containing 18–20 per cent moisture that is clean and has been harvested without excessive damage can be kept for short periods in sacks which are spread out in a well-ventilated building, but it can rapidly give trouble in warm, damp weather. At 16 per cent moisture content sound grain can be stored fairly safely in sacks, and may be put into unventilated bins if it is watched and turned occasionally. At 15 per cent moisture content, sound wheat will keep safely in bulk, and needs only an occasional check to ensure that there are no troubles arising from damper patches or from insect infestation. Barley needs to be a little drier than wheat to be equally safe, and it is best dried to 14–14½ per cent moisture for bulk storage. Most progressive farmers who can afford to do so, while hoping for and making the most of a season that enables them to harvest most of the grain at a moisture content suitable for storage, will plan for an average or bad season that makes conditioning of some of the grain essential.

The amount of drying needed, while depending to a great extent on the season, can also be considerably influenced by management of the combine harvester. On a summer day in good weather, grain that is fully ripe and has not recently been wetted by rain may have a moisture content of 19 per cent in the early morning. Moisture will then evaporate fairly rapidly from a standing crop, and by late afternoon the grain may contain under 16 per cent moisture. This emphasises the need for adequate combine harvester strength, so that the work can usually be carried out in favourable conditions. Another important factor in management is choice of early-maturing varieties of cereals, which ripen when the days are long during the early part of the season.

In any mass of grain as it comes from the field, the volume of air between the individual grains in a bag or in a bin is almost as great as the total volume of the individual grains. This air, if stagnant, very rapidly takes on a degree of dampness corresponding to that of the grain itself—a characteristic made use of in one form of grain moisture meter, which measures the relative humidity of the intergranular air. All farm grain driers operate on the principle of blowing away this moisture-laden air and replacing it by relatively dry air which can take up more moisture from the grain before it is in turn expelled. The vast differences between grain driers arise from the considerable variations in the thickness of the grain layer, the dryness of the air used, and the speed at which the air is blown through. Choice of drying system depends on a large number of factors some of which are mentioned below in describing the characteristics of common types of plant.

Continuous-flow Driers. A characteristic feature of these machines is a grain layer only 3–6 in. thick, with arrangements for moving it continuously through the drier. The most common type is in the form of a short tower down which the grain flows by gravity; but horizontal conveyors and inclines are also employed. Some horizontal conveyor machines are suitable for either grass or grain drying. Drying is rapid, the grain usually staying in the machine for less than an hour, during which time 5–6 per cent moisture might be removed, at a throughput ranging from ½ to 20 tons per hour. In order to achieve maximum throughput, continuous driers usually employ the highest temperatures that can be maintained without damaging the grain. These maximum safe temperatures are as follows:

	Max. Temp. ° F.
Corn for stock feed	180
Milling wheat	150
Malting barley or seed corn of under 24 per cent m.c.	120
Malting barley or seed corn of above 24 per cent m.c.	110

Continuous driers are usually fairly expensive in capital cost. Running cost depends partly on such factors as the fuel used, oil-fired heaters being most popular; but depreciation and interest charges inevitably outweigh both fuel and labour costs if an expensive installation is little used.

With a continuous drier it is usually advisable to arrange not only for pre-cleaning of the grain but also for some pre-drying storage of grain, so that the machine can operate with little labour for long hours if necessary. A drier with a throughput of 1 ton per hour when removing 6 per cent moisture at 150° F. will be capable of dealing with the produce from two large combine harvesters in most areas and seasons.

With all "high-temperature" driers, including some tray machines, it is essential to cool the grain to within 10° F. of atmospheric temperature before storing it in bulk.

Tray Driers. Horizontal tray driers with trays having perforated floors are suitable for drying grain in layers 1–2 ft. deep. Dual-purpose (grass and grain) driers employ temperatures similar to those used in continuous driers, but owing to the fact that the grain is not moved during drying it is advisable to keep maximum temperatures 10° F. lower than those given for continuous-flow machines above. Drying at the higher temperatures tends to be uneven, but subsequent mixing of the grain during emptying minimises the disadvantage.

Tray driers employing temperatures not more than 25–30° F. above atmospheric temperature dry the grain slowly and safely. Handling the grain into and from the tray may be facilitated by the use of a tipping mechanism or by having the tray permanently inclined at an angle of 15–20 degrees. Throughputs of portable tipping tray low-temperature driers are from 1½–2 per cent moisture extraction per hour from 25 cwt. to 3 tons of grain, while a typical output of a high-temperature dual-purpose drier is 5 per cent removal per hour from 1½ tons.

Platform or In-sack Driers. This simple and cheap type is suitable for many farms where the volume of grain to be dealt with does not justify an expensive installation. The damp grain, contained in partly filled bags of open-weave hessian, is placed over metal grids covering suitable apertures in the top of a platform beneath which warm air is blown. The grain layer should be about 9 in. thick and a temperature rise of 25–30° F. above atmospheric is generally suitable. Advantages other than the cheapness in capital cost are that it is almost impossible to damage grain by this drying method, and that any type of grain or seed crop can be dried. The extent of drying is controlled simply by varying the duration of the drying period, and this makes the method equally suitable for removing much or little moisture. Typical outputs range from 1 per cent moisture removal per hour from a 3-ton batch down to ½ per cent per hour from a 1-ton batch. The former size is usually oil-fired, while the smallest are almost always all electric.

The simplicity of this method of drying often tempts farmers to underestimate its effectiveness, or to neglect thorough planning of the layout when a drier is installed. It is advisable to plan layouts carefully, since mistakes may result in difficulties in operation and an unnecessarily high labour requirement. It is usually advisable to provide a generous amount of floor space at the same level as the platform top, for storing corn in bags both before and after drying.

The grain is never quite so dry at the tops as at the bottoms of the bags, but the difference soon disappears, especially if the grain is mixed by being cleaned after drying.

In the early days of development of platform driers farmers had to build their own platforms. Several manufacturers now offer packaged units consisting of pre-cast concrete components all ready for erection ; and the only outside help needed is for a qualified electrician to connect up to the mains where an electrically operated plant is chosen.

Vertical-flow Ventilated Bin Plants. In this type of installation the grain is dried in the storage bins, and the plant serves the dual purpose of providing for both conditioning and storage. For this reason it is more expensive to instal than a simple drier. The drying bins are provided with perforated or porous floors, and slightly warmed air is blown through the grain from the bottom to the top of the bin. Grain depth during drying normally ranges from 2 to 10 ft. and an air temperature rise of 6–10° F. above atmospheric is generally employed. The aim is to keep the relative humidity of the drying air at 55–60 per cent and this results in the grain having a moisture content of about 14 per cent. There is no need to keep the relative humidity absolutely constant, since slight over-drying by air of low relative humidity during the day is balanced by the higher relative humidity at night. Occasional tests of the moisture content of the grain near the bottom of the bin suffice to indicate the need for any adjustment of the temperature rise, and such adjustments can easily be made in the last few days of drying.

A properly designed ventilated bin plant is a sound method of providing grain storage in any part of the country where the bulk of the grain can normally be harvested at a moisture content of 20 per cent or below. Ventilated bins can deal effectively with very damp grain, but only in relatively small quantities which are treated in shallow layers. It is advisable to provide all bins with ventilated floors and to be able to provide an air flow of 15–20 ft. per minute simultaneously through at least half of the bins when they are filled with grain to a 10 ft. depth. In wet regions, provision of 20 ft. per minute through two-thirds of the bins simultaneously may be advisable.

Typical performance in a well-designed plant ranges from removal of 5 per cent moisture in 10 days from a single 20-ton bin filled 10 ft. deep, up to removal of 5 per cent in 5 days from half a dozen or more 20-ton bins where the grain depth during drying is limited to 5 ft. The first requires a small fan which can also do the pneumatic conveying for a 40–60 ton plant, while in the latter case a very powerful fan is required and conveying must be done by other means.

Drying in a vertical-flow ventilated bin is effected from the floor upwards. When a fairly damp batch needing 5 per cent moisture content removal is being dried, the situation after 2–3 days is that the bottom 2 ft. is perfectly dry, drying is proceeding in the layer 2–3 ft. from the bottom, and the upper part is substantially unchanged. Ventilation should not be interrupted until the grain at the top is dry, and it is then advisable to turn the grain once in order to secure thorough mixing. This turning is unnecessary for grain put in the bin fairly dry, but desirable if any grain was put in very wet.

There is no limit to the size of a ventilated bin plant, but it becomes desirable to consider the alternative of a continuous drier or of splitting the ventilation system at storage capacity above the region of 400–500 tons. The system can be adapted in the smaller sizes to suit a wide range of existing buildings, but it is often preferable to put the plant on a clear site, owing to the extent of the strengthening and alterations needed.

Any farmer who considers installing a plant is well advised to seek up-to-date information on such matters as general layout, bin and floor construction, methods of warming and controlling the air and efficient operation.

Other Ventilated Grain Storage Systems. In the radial-flow ventilated bin system the drying air is introduced into the centre of the cylindrical silos through a drying cylinder, with perforated walls. The air then flows outwards through the grain, and leaves the silo through perforations in the walls, which may be made of expanded metal, hessian supported by a suitable steel mesh, or louvres of various kinds. A typical drying silo is 7–10 ft. in diameter and has a central cylinder about 1 ft. 6 in.–2 ft. in diameter. The relatively thin walls of grain through which the air has to pass can result in high efficiency and a drying rate appreciably greater than that usual in vertical-flow ventilated silos. For example, the removal of an average of 2 per cent moisture per day from a 7 ft. 6 in. diameter silo is fairly easily achieved. In one type of ventilated bin plant the warm air is introduced and the damp air exhausted at various levels through the silo. The thickness of the grain layer between inlet and exhaust ducts is thereby limited to about 5 ft., and a fairly high temperature rise (e.g. up to 25° F.) or chemically dried air may be effectively employed. This makes it possible to remove from 2 to 5 per cent moisture content per day from a single 20-ton bin, and with such an arrangement it is advantageous to have a few self-emptying drying bins, together with plain bins for subsequent storage. Uneven drying may be partially avoided in self-emptying bins by arranging a limited amount of grain circulation.

A method of drying that suits some farmers who do not wish to build bins is to lay portable louvred ducting on a barn floor and blow slightly warmed air through the grain which is piled to a depth of usually 5–6 ft. above the ducting. If this method is employed on a big scale it is advisable to arrange the main duct in such a manner that distribution of the air to different parts of the grain mass can be effectively controlled by shut-off valves. Most farmers who wish to store grain on barn floors find it best to dry it in a continuous-flow machine beforehand.

Grain Cleaning. In weedy crops, or where a short-strawed barley is undersown with grasses and clovers, a considerable amount of greenstuff may be taken into the combine harvester with the straw, and broken pieces of leaves, thistle heads and many insects are often present in the grain sample. The greenstuff, along with dust and broken pieces of straw, tends to collect in patches that will quickly heat if the grain is stored in bins. Pieces of straw will also cause trouble in some types of drier by preventing an even flow of grain through the machine. It is therefore essential with tower driers and also with ventilated bins to remove most of the rubbish by passing the grain through a " pre-cleaner ".

The term " pre-cleaner " is applied to various types of machines designed to remove the impurities referred to above, and not necessarily expected to make a properly graded commercial or seed sample. Nevertheless, there is no fundamental difference between some types of pre-cleaners and a complete corn dresser. A pre-cleaner usually employs one or more of the following devices :

(*a*) An inclined reciprocating screen with large holes to remove pieces of straw, thistle heads, string and other roughage.
(*b*) An air blast to remove dust, chaff, and light or broken grains. This may be provided by a simple winnowing device or by a controlled aspiration in what is termed an aspirating leg.
(*c*) A screen with small holes to separate small and broken grains and weed seeds.

A combined cleaning and grading machine may employ all the above devices and it may also incorporate certain other mechanisms such as :

(*d*) A rotary screen to separate grain according to its width.
(*e*) Discs or indented cylinders with pockets to separate grain according to its length.

A good pre-cleaner should be capable of operating for long periods without blockage of any screens that are employed ; points to look for are ample capacity and a fairly steep angle of slope on the screens, together with suitable arrangements for disposing of the large amount of dust that may be removed in the cleaning operation. The latter requirement is often best met by machines which employ one or more aspirations and deliver the light liftings through a duct to the outside of the building.

On many farms it is advisable to select a machine that is capable not only of carrying out any necessary pre-cleaning, but also of preparing a commercial sample after drying or storage.

Grain Conveying. It is possible on a small scale to treat grain in batches without the use of any form of conveyor, but where the amount to be handled is considerable it is usually essential to employ power operated conveying equipment to move the grain from a receiving hopper to and from cleaning or drying equipment, and into or out of bulk storage.

Bucket Elevators are simple in design, easily repaired and adjusted ; they are widely used for vertical lifts for feeding cleaners and driers, for filling silos near the elevator, and to link upper and lower horizontal conveyors used for delivering to distant storage silos. They need a separate pit when used to empty underground receiving hoppers. The foot is not self-cleaning.

High-speed Auger—some designs are suitable for vertical or horizontal use, but generally these systems are employed either fixed or portable, for conveying in inclined positions. They occupy little space, little or no extra height at head or foot. With some models the foot can be dropped directly into the mass of grain.

Chain and Flight, Oscillating (Shaker) and Belt Conveyors are used for horizontal runs. The oscillating type needs a firm mounting but has considerable advantages in cheapness and simplicity. Short belt conveyors can be movable where necessary. Some chain and flight types and belt and flight conveyors are suitable for use in an inclined position.

Pneumatic Conveyors can provide a complete conveying system from a single fan, and are often suitable where electrical power is not available, or where long and complicated horizontal runs are involved. Power requirement is high, the conveyor is noisy and tends to create a dusty atmosphere. The drive unit can be made easily portable.

In choosing a conveyor for a small or medium-sized installation, the advantages of a completely automatic press-button arrangement must be considered in relation to the cost. The annual usage is always likely to be small, and a considerable saving in capital cost can sometimes be made by accepting the need to spend a little time in moving a part of the equipment.

EQUIPMENT FOR PREPARING RATIONS

The introduction of new grain-harvesting methods, the extension of rural electrification and the development of new types of equipment for corn grinding and meal mixing, have combined to make many old granaries unsuitable or at least inconvenient for modern needs. Where the basis of the stock rations is to be home-grown corn harvested by combine, it is very desirable to site the food-preparing plant adjacent to the grain store, so that a short extension of the conveying system provides for easy transfer of the grain for grinding.

It is often possible to house a new bulk grain store in an existing barn adjacent to the granary, but where the grain store has to be built on a new site, the provision of grinding facilities there should be considered.

An existing two-storey building can be put to good use for food preparation, and valuable covered space at the end of a high barn used for grain storage can also often be most efficiently utilised by putting in an extra floor ; but with modern equipment sited adjacent to a bulk grain store there is no other important advantage in a two-storey arrangement, and a single storey layout is likely to be preferable. In either case it is usually advisable to adjust floor and road levels so that there is one loading and unloading point which has the granary floor at the level of the platform of a lorry standing outside the building. This facilitates loading and unloading with a sack barrow.

Where mains electricity is available it is always better to use it for all farm machinery, equipping each machine with its own motor, and making use of the freedom that this bestows, to locate each machine in the best possible place. In order to keep electrical loadings and capital costs within reasonable limits it is advisable to choose machines of small capacity and to arrange them for unattended operation wherever this is practicable.

Grinding and Crushing Mills. The main types of mills now used on farms are :

(*a*) Plate mills in which the corn is ground between the surfaces of two corrugated plates made of chilled cast iron.
(*b*) Crushing mills in which the grain is rolled between the surfaces of two iron cylinders that rotate close together.
(*c*) Hammer mills in which the corn is disintegrated by being struck by steel hammers which rotate at high speed inside a casing.

A popular machine in the past has been one incorporating both chilled-iron grinding plates and crushing rollers, but the use of small automatic hammer mills has extended rapidly with the provision of electricity supply. These machines have a low power requirement, can easily be made to operate unattended for long periods, and are low in capital and maintenance cost. The usual method of control is to put the required quantity of grain into the hopper and set the mill running. The mill switches itself off when the grain hopper is empty. By the use of interchangeable screens the hammer mill can do either coarse or fine grinding. Some farmers prefer to roll oats in a crushing mill for cattle or horses, but on many small farms only an automatic hammer mill is employed.

The mill needs a grain hopper of at least 10 cwt. capacity, and this may be bought from the mill manufacturer or made up on the farm. Where it is necessary to feed grain into the hopper from sacks, the top of the hopper can be about 18 in. above floor level and the mill itself sunk into a shallow pit. Mills of up to 5 H.P. are normally arranged to blow the grain into one or more meal bins equipped with a filter-cloth top. When larger mills are used it is almost essential to have a cyclone, but this can be arranged to deliver into bins if required. It is difficult to make meal flow freely out of storage bins, and the most satisfactory form of construction is to have parallel sides and a gently sloping bottom which leads to a large vertical bagging-off slide. The slide is protected from the weight of the meal by an inclined board fixed above it, and a short rake can be used to bring the meal forward to the bags if necessary. Fig. 17 shows a typical installation which is capable of an output of up to about 5–6 tons of meal per week.

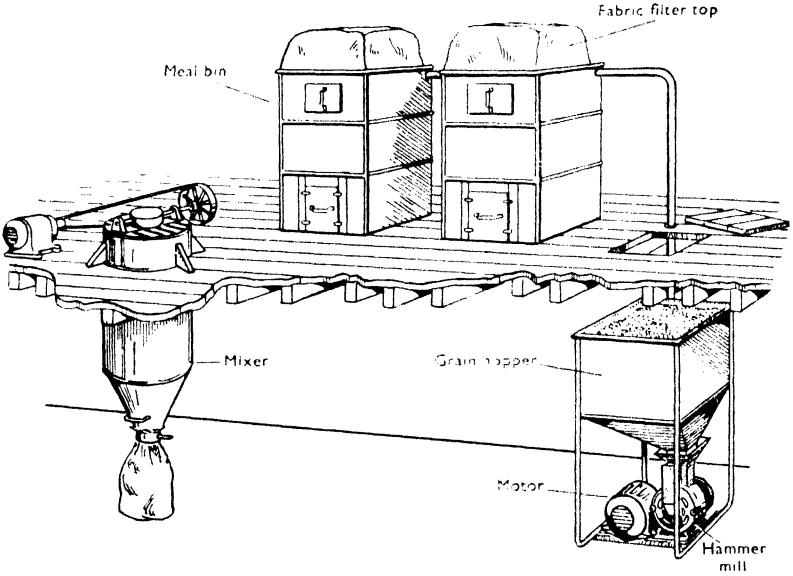


FIG. 17.—TWO-STOREY ARRANGEMENT FOR GRINDING AND MIXING RATIONS.

[*Christy and Norris*]

Food Mixing. A mechanical food-mixing machine is rapidly becoming a regular item of equipment, and the type now generally preferred is a bottom-feed machine which employs a high-speed auger to take in the ingredients and throw the mixture over the top of the mass inside a conical casing. Where the drive is by electricity the motor may be mounted at the top of the machine itself, and this helps by leaving the floor space clear. The mixer is started up when the first sack of ingredients is tipped in, and by the time the whole of a batch has been loaded, mixing is usually almost complete. A mixer of 10 cwt. capacity is large enough for most farms. If desired, a small hammer mill can be arranged to blow the meal directly into the mixer. It is usually advisable to provide the latter with an outlet at the top which leads to a fabric filter of adequate size, but some manufacturers provide for complete re-circulation of air back to the mill. In a well-arranged food-preparing plant, ample floor space is provided for storing bought-in feeding-stuffs that are to be mixed with the home-grown meal, and also for the temporary storage of mixed rations.

SERVICES

Water. To make the fullest use of a farm an adequate supply of pure water to buildings and fields is essential. Apart from public water mains, sources of a farm supply are deep and shallow wells, bore holes, springs, streams, ponds, ditches and rainwater. Wells and bore holes require pumping plant and some form of storage. Where a supply by gravity from springs and streams is impossible a *ram* and sometimes storage will be necessary, though in the fields properly constructed watering places in a stream can be satisfactory. Ponds and ditches are unreliable sources of water and are liable to spread disease through pollution. Rainwater rarely provides an adequate supply and is more useful as a supplement to other sources.

Pumps. Before deciding to use any source the adequacy and purity of the water should be fully tested, and with shallow sources steps must be taken to prevent pollution by surface water. For farm supplies a reciprocating pump (suction, lift or force) is generally the most suitable as it usually requires no priming and will work with a high suction lift. For bore holes, a submersible form of turbine pump, working in stages, is required. Pumps can be driven by electric or internal combustion engines or a windmill. Where a supply of electricity is available an electric motor has many advantages on grounds of cost and ease of operation as it can be controlled automatically by switches in the storage tank, and only a small pump house is required to house them.

Pumping can be either to a storage tank or reservoir situated at the highest point in the system, with distribution from it by gravity or into a small pressure tank close to the pump. Elevated storage tanks are often costly and a reservoir at or below ground level is to be preferred ; they should be capable of holding two or three days' requirements and to make them larger is expensive and unnecessary with an adequate supply. Requirements can be calculated from the following average figures of consumption :

WATER REQUIREMENTS PER HEAD OF LIVESTOCK

Cows in milk	15	gallons	per day
Cooling and cleaning utensils, etc.	15	,,	,,
Other cattle and horses at work	10	,,	,,
Pigs	3	,,	,,
Sheep	1½	,,	,,
Poultry in batteries	⅛	,,	,,
Domestic houses sewered	20–30	,,	,,
Domestic houses unsewered	15	,,	,,

Pipes and Troughs. The pipes of the distribution system should be laid 2½ ft. deep to avoid frost damage and there should be sluice valves to all main pipes. The materials most used for pipes are plastic (polythene), galvanised steel, copper and asbestos-cement. Plastic and copper pipes are available in long coils and can be most easily laid by a mole plough which avoids the expense of excavation work. Galvanised steel can also be laid with a mole but it is sometimes damaged ; it is cheap, but on the other hand it corrodes rapidly in some soils and with some waters. Copper corrodes much less readily but is more expensive. Asbestos-cement pipes may also be affected by corrosion at the metal joints unless they are protected, but otherwise they are cheap though only available in 1½ in. sizes upwards. The expense of a distribution system to each field can sometimes be saved if only a central main is laid : it is provided with points to which troughs, placed in each field being grazed during the season, can be connected by a length of plastic tubing laid along the ground.

Pre-cast concrete troughs for livestock are the most durable. To prevent damage the ball valve should be in a separate locked compartment at the end or centre of the tank with the supply pipe entering from the bottom. The pipe should be fitted with a stop cock so that the water can be turned off when necessary. A surround of hardcore or clinker prevents poaching of the soil by cattle. The number of troughs can be reduced by placing them in the dividing fence to serve two fields.

DRAINAGE

The disposal of foul water from the farmstead is often made unnecessarily difficult because large quantities of relatively clean water are allowed to mix with it. All buildings should have eaves gutters and down-pipes leading by underground drains or open channels to soakaways or a near-by ditch, and the system should be kept in good order otherwise the damp will progressively damage walls and foundations and mud and puddles will develop round the farmstead. Yards and other paved areas should also have proper drains connected if necessary to the same system, and when higher ground slopes towards the farmstead there should be open channels or drains to divert the storm water. Careful use of water in the farmstead can save money and disposal problems ; cooling water from the dairy can be re-used for drinking or washing down, and the swilling down of cowsheds and piggeries can be restricted and this will also save condensation and other problems caused by excessive humidity.

Liquid Manure Tank. Where the bedding in livestock buildings will not absorb all the liquid, the floors should be sloped to open channels leading to gulleys with a trap, situated outside. The gulleys will in turn lead to a drain of socketed glazed pipes, 4 in. or 6 in. in diameter according to the number of gulleys discharging into them. The sewage from the drain can either flow into a tank in which the liquid manure is kept for spreading over the land, or more often into a cesspit. A liquid manure tank should be large enough to contain at least one month's flow as more frequent emptying can be inconvenient. It is usual to reckon the daily quantity of urine at 3 gallons from each cow, 1½ gallons from other cattle and ½ gallon from pigs. To prevent the liquid manure being diluted too much there should be double gulleys at cowhouses (see Fig. 4) so that washing water will flow into the water drains. Tanks can be of brickwork, reinforced concrete or large concrete tubes on a reinforced concrete base. They should be airtight to prevent loss of nitrogen and there should be a removable cover in which a diaphragm pump can be inserted to empty the tank into a distributing cart ; where levels are suitable, emptying can be by gravity flow. A settling chamber is sometimes provided to collect solids such as straw before the liquid goes into the collecting tank.

Where no bedding is used, as in a building with slatted floors, the liquid manure and dung will be mixed together and can either be kept in a chamber underneath the slatted floor or piped into a storage tank. In the *Gülle system*, adopted from the Alps, the tank is open and is fitted with an agitator to mix the contents. The mixture is diluted with water and then spread on the land either from a liquid manure distributing cart or through an irrigation plant (see p. 207).

Cesspit. If a cesspit is to be used the local authority should be consulted as to the size of tank and method of disposal which they will accept. Sometimes a tank smaller than a liquid manure tank is sufficient. The liquid coming from it may have to be filtered before it goes to a disposal point such as a ditch. The filter can be either a bed of gravel or broken brick or a number of lengths, each at least 100 ft. long, of 4 in. diameter field drain pipes laid in a bed of clinker and distributed at a depth of 1 ft. 6 in. or more over a suitable field. Sewage from the farmhouse and cottages should always be kept separate from the farm drainage as it needs different treatment.

Silage Effluent. The disposal of the effluent from silage often presents a serious problem. It has a very high oxygen demand in water and as a result causes the death of fish as well as of plants and trees near streams which it has been allowed to contaminate. The effluent can also cause the blockage of field drains, to which it penetrates, by fungal growth. The amount of effluent coming from the silage can be minimised by protecting the silage from rain and by ensiling only wilted crops of high dry matter content. In this way the effluent can be reduced from as much as 80 gallons per ton of silage to as little as 1 or 2 gallons. Where there is only a small quantity of effluent it can be taken to a small soakaway sited where there is no risk of pollution. In other cases the only solution is to construct a tank and to pump out the diluted effluent and distribute it over the land as liquid manure.

ELECTRICITY

Electricity from the public supplies is normally at 240 volts pressure with a current alternating at 50 cycles a second. The supply can be single phase or three phase ; the single-phase system is the cheaper to extend to a farm as it requires fewer wires at the transformer and throughout and so it is what electricity boards usually provide. A single-phase supply is adequate for most farm purposes such as lighting, heating and driving small motors. Three-phase motors are cheaper than single phase owing to the simpler starting but the difference only becomes appreciable in sizes over 10 h.p. Where only a single-phase supply is available it is cheaper to use a number of small automatically controlled motors rather than to do the job more quickly with a large motor. For example, a 3 h.p. small hammer mill running for five hours to grind a ton of meal will cost no more to run than a large 20 h.p. mill grinding the same quantity in 1½ hours. For crop drying where heavy loads are involved, or where large motors are essential, a three-phase system would be required.

Where a mains supply is not available, engine-driven generating sets can be used. A plant generating alternating current at 240 volts is the most suitable for farm use and has the advantage that no changes in wiring and appliances are involved when a mains supply becomes available. It is, however, impossible to store alternating current so that the plant has to run all the time that electricity is required. In a direct current system storage batteries, recharged by the generator, can be used ; batteries are, however, expensive particularly for a high voltage. A 3–5 K.V.A. diesel plant will supply lighting and drive most small motors on a farm, especially if arrangements can be made not to use the larger motors at the same time. Starting can be automatic whenever the current is switched on, remote control or manual. Water and wind power can also be used to drive small generators.

Wiring in farm buildings is mainly done with plastic conduit, plastic cable or with self-contained tough-rubber-sheathed (T.R.S.) cable of which there is a special form with an impregnated outer braiding known as farm wiring cable. It is fixed by special wiring clips and cleats and being flexible there is no difficulty with irregular surfaces. The wiring is less likely to be damaged if it is fixed as high up as possible and out of reach of livestock and other sources of damage. In positions where abrasion may occur the cable can be enclosed in steel channelling or in conduit. Electrical wiring, is, however, a matter for the expert and advice should be obtained on the most suitable form of installation. British Standard code of practice No. C. P. 325 (obtainable from the British Standards Institution) has useful information about wiring as well as other matters concerned with electricity on the farm.

Further mention of the use of electricity on the farm is made in Chapter IV.

ROADS

Traffic using roads on a farm is relatively light and infrequent so fairly simple methods of construction are all that is required. It is important to appreciate that it is the soil which supports the weight of the traffic, and everything possible should be done to improve the load-bearing strength of the soil. The soil, however, needs to be kept dry if it is to bear the weight of traffic without sinking. Rain falling on the road should be removed quickly by making the surface as impervious as possible, and by sloping the road so that the water will run off to the sides, preferably into grips or channels which will carry it well clear of the road and its base. Shallow side ditches close to the road are ineffective and may do more harm than good. In places where the water table is high, deep side ditches may also be necessary to keep the ground water away from the road. Except for clay, the soil should be well rolled or compacted to increase its bearing capacity by removing air voids, a heavy roller (not less than 50 cwt.) being used after vegetation or turf have been removed ; it is unnecessary to remove any soil. Road work should be carried out when the soil is as dry as possible, that is, during the summer and autumn.

Some soils, mainly gravels and sands with well-graded particles, will, with shaping and consolidation, form a satisfactory farm track provided it is reshaped periodically when it gets worn. Roads of this type will give better service if the surface is waterproofed by dressing with bitumen, blinded with ¼-in. stone chippings. Normally the bearing capacity and wearing qualities of the soil have to be improved by the addition of several layers of stone or similar material to form what is known as a *flexible pavement*, or by putting down a slab of concrete.

In a *flexible road* the choice of materials for the various layers will make a lot of difference to the cost. Hard, crushed stone or macadam make the best road, but it is usually the most expensive and local materials should be used wherever possible to save cost. The first layer lying on the soil is the *sub-base*, about 2 in. thick, which levels out the surface of the soil and acts as a cushion between the soil and the main layers of the road. It can be of clinkers, gravel or cinders. The next layer is the *base*, of any thickness from 3 in. upwards, though anything over 4 in. is unnecessary on most farm roads, and costly. It is usual to specify that the thickness of the base should not be less than twice the size of the largest stone in it. Crushed stone may be used or such local materials as flints, chalk, builders' hardcore, cinders, clinkers or slag. The top layer is the *surfacing* or *wearing course* which provides a smooth surface for traffic and protects the layers below from wear and the effects of the weather. The simplest way of surfacing is to " blind ", or scatter and roll over the base, a layer of fine material such as stone dust, gravel or ash. An improvement is to waterproof the surface by binding it with a water slurry of stone dust or of sand and clay. An alternative to water binding is to surface the road with fine material of not more than 1½ in. size, grouted with tar, bitumen or bitumen emulsion, followed by a blinding of fine grit. The tar and bitumen have to be applied hot and so need special equipment which is probably not worth hiring for a short length of road. Bitumen emulsion, although more expensive, can be applied cold without special equipment. Stone can also be bought already coated with tar or bitumen. Although the various layers have been described separately, in practice they are often combined and laid in one or two layers.

The flexible road needs maintenance if it is to last. Mud and animal droppings must be removed from time to time and pot holes and depressions filled with material similar to that used originally, and grouted with bitumen. Complete resurfacing will be required eventually but what has to be done then will depend upon the condition of the road. At the worst, the base may have to be renewed in places and a complete new surfacing applied. In other cases only the surfacing will need filling up and shaping, though if a heavy roller is available the surfacing should first be scarified or broken up.

Concrete roads on a farm are often made too thick. Normally a thickness of 4 in. is sufficient though 6 in. may be required for really heavy traffic. Hardcore under the concrete can also be omitted unless the soil is very wet and unstable. The mix should be by volume, 1 part of cement to 2½ parts of sand and 4 parts of gravel or crushed stone well graded up to 1½ in. in size. Steel reinforcement is not usually required in farm roads, and special joints are unnecessary if the concrete is laid in alternate bays about 15 ft. wide.

A cheaper version of a concrete road is often possible with soils coarser than clays and free from much organic matter. This is the *soil cement road* which consists of a mixture of soil and 10 per cent cement (1 cwt. cement to 2 square yards of soil 6 in. thick). The cement is spread on the soil when dry and is well mixed, watered and rolled. After the road has had time to cure, a bituminous surfacing is applied. The suitability of soils for this kind of road can be determined by laboratory tests or more simply by laying a trial section with a bag of cement.

The choice of road will depend largely on cost, and the cheaper the road the more maintenance it will need. The approach road to a a farm should be as smooth as possible, and if traffic can be restricted mainly to vehicles with rubber tyres a flexible road with a bituminous finish or the more expensive concrete road is often the most suitable. Around the buildings concrete is required as it provides the only surface which can be kept clean without damage. Tractors and implements not on rubber tyres, cattle and sheep will damage roads with bituminous surfacing so that for roads leading from the farmstead to the fields a simple form of flexible pavement is required, or concrete, if the extra cost can be justified.

Farm roads are generally 9 ft. to 10 ft. wide, but this is not strictly necessary and a road 7 ft. 6 in. wide gives a track wide enough for most traffic and saves cost ; an occasional passing place is desirable and fencing should be set well back from the road.

FENCES

There are four main types of farm fence—post and wire, post and rail, hedges and walls ; the last two are valuable also for the shelter they give, particularly in exposed districts.

Post and wire fences are the cheapest and can be either of single wires or of woven wire. To be satisfactory the wire fence must be strained very taut and for this there should be stout, well-strutted straining posts at intervals of not more than 150 yards and at all changes of direction. The posts should be fitted with eye bolts or ratchet strainers so that the wires can be tightened when necessary. Straining posts should be 7½ to 8 ft. long and 5 in. × 5 in. in section, with one-half to one-third embedded in the ground. Intermediate posts or stakes are spaced at 10 to 12 ft. intervals, though this can be increased to 30 ft. if droppers (spacing bars of steel or timber 1½ in. square to which the wires are nailed at 6 ft. intervals) are used. A pointed stake of 3 in. diameter and 5 ft. 6 in. in length driven 1 ft. 6 in. into the ground is usual.

Timber posts if not of oak, larch, chestnut or cedar should be treated with creosote either under pressure or by the hot-and-cold open tank method. With the open tank method the timber is placed in a tank of cold creosote which is heated to 180–200° F. After keeping this temperature for 1 to 2 hours the creosote is allowed to cool and the timber is then removed. A gallon of creosote to each cubic foot of timber is required, but very absorbent timbers will take 3 gallons. This is unnecessary and adds to the cost, but some of the creosote can be recovered if the tank is again heated and the timber is removed before the creosote cools. Any watertight tank is suitable, and for fencing posts an oil drum large enough to take the butts up to ground level will suffice.

Angle iron and concrete posts are satisfactory but concrete should not be put in places where it may be knocked by implements. A tractor driven post-hole borer reduces the labour of putting in posts and there are also devices for making it easier to drive them in.

Single wire fences can be of three to seven wires, of which the top, bottom and not more than one intermediate wire need be barbed. Other wires should be plain : 8 to 10 gauge is sufficient thickness except in areas where corrosion of steel occurs. The top wire should normally be 3 ft. 9 in. above the ground. Woven wire fencing is available in various widths and spacings of the wires for pigs, sheep and cattle ; it is more stock proof if a strand of barbed wire is fixed at the bottom and top. Woven wire fencing is more expensive than plain wire but it is easier to erect and lighter posts are sufficient.

An inexpensive form of dropper fence is the *lightning* or *spring* fence, common in Australia. Strainers are spaced 220 yards apart and the intermediate posts are 30 to 55 yards apart. Light gauge high tensile wires are used, strained very tight and kept apart by cleft chestnut palings every 2 to 4 yards.

Post and rail fences last longer than wire fences but are two or three times as costly. The most durable type consists of three or four rails morticed into posts spaced at 9 ft. centres with an intermediate or prick post in between. The timber should be well treated with preservative. Cleft rails nailed to split round poles provide a cheaper fence, and cleft timber lasts longer than sawn.

Hedges are three or four times as expensive as wire fencing but have a much longer life. Many varieties of plants are suitable but hawthorn (quickthorn or *Crataegus oxyacantha*) is the most used under a wide range of conditions. The hedge should be planted on the flat with the plants spaced 9 in. apart in a double row and a good ditch provided where necessary. Wire fences to protect the young hedge against livestock are often required. The cost of planting can be reduced by using farm implements instead of hand digging to prepare the bed. Tractor-operated hedge trimmers make subsequent trimming cheaper ; they are no substitute for the laying by hand every ten to fifteen years required for a good stock-proof hedge which has been previously laid.

GATES

The traditional timber five-bar gate 10 ft. wide and 4 ft. high is still very popular on the ground of cost and durability. Many kinds of timber can be used but they should all be treated with preservative, even oak and larch. The important parts of a gate are the top rail or *bar*, the *heel* and the *head*, which should be of oak or larch well morticed together. Only the top, bottom and one other bar should be morticed through the heel and the head to avoid weakening them, and the gate should be well braced with diagonal struts and braces bolted rather than nailed together ; a diamond pattern for the bracing is often preferred.

Hanging posts of timber or concrete should be 8 in. square in section and 7½–8 ft. long, set at least 3½ ft. in the ground. A gate will sag in time and it helps to have adjustable hinges. Gates should be hung to be self-closing, and it is an advantage to have a latch which will support them when closed.

Wider openings of 12 ft. upwards are required for modern implements but timber gates of over 10 ft. are too heavy. The solution is to have two gates 7, 8 or 9 ft. wide which either meet at the head or else overlap and can be locked together by a swinging bar. An alternative is a wide tubular steel gate which is lighter than a timber gate. A steel gate should be well galvanised after manufacture and painted with bitumen if it starts to rust. Angle iron gates are also satisfactory

GRIDS

A cattle grid is a convenient way of providing a barrier to livestock in a road where a gate is liable to be left open or is a nuisance. It consists of a number of bars fixed across the direction of the road over a shallow pit about a foot deep. The bars are spaced 5–6 in. apart, which is sufficient to deter animals from crossing but does not hinder wheeled traffic. A grid should be the full width of the road and for farmstock a length of 6–8 ft. is sufficient. There should be fences along either side of the grid to prevent animals getting round (Fig. 18). A number of inexpensive proprietary grids in concrete or steel are available. Grids can be simply constructed of 2-in. water tubing or 3 in. × 3 in. rolled steel joists fixed to concrete or timber bearers.

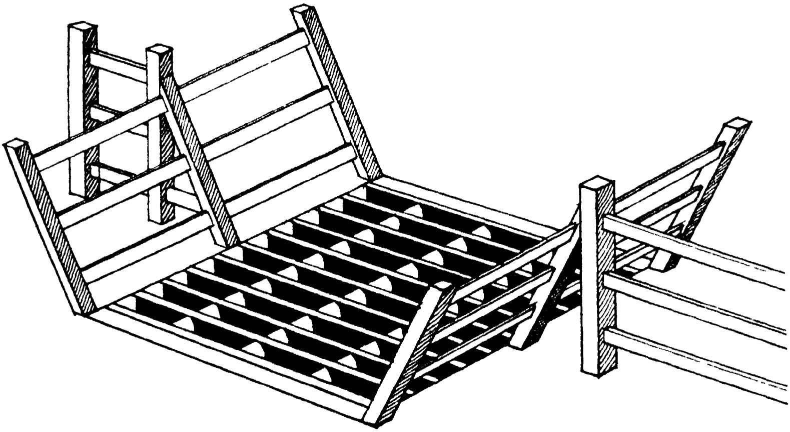


Fig. 18.—Cattle Grid.

Chapter IV

THE USE OF MECHANICAL POWER IN FARMING

THE farmer uses mechanical power and machinery either to increase food production or to maintain a given volume of production at a smaller cost. This problem is essentially the economic one of how to organise use of his labour and equipment in the most profitable way. Power and equipment costs today represent an important and increasing proportion of total farm costs, and vary widely from farm to farm. It is clearly important that farmers should have such a knowledge of power and machinery as will enable them (1) to choose and buy equipment well suited to the needs of the farm; (2) to understand the working principles of the machines so that they may be kept in good running order; and (3) to understand the applications of the equipment in order that it may be operated efficiently.

The power of animals has been used in farming from the earliest historical times. In Britain, use of animal power has now passed its peak, and the working horse has become subsidiary to mechanical power. As mechanical ingenuity developed, and Britain became industrialised, increasing use was made of water and wind power on farms, especially for the driving of grinding mills. Water power is still used where circumstances are especially favourable, and there are also many wind-powered pumping plants in constant use. When the steam engine was developed it was, naturally, harnessed to agricultural jobs, and was successfully used for heavy cultivations and threshing; but steam power on the farm has had its day, and is now generally superseded by the much handier power of the internal combustion engine and the electric motor.

Internal Combustion Engines. Internal combustion engines are today of prime importance in British agriculture. Three main types of engine are used on farms, viz. petrol, paraffin and Diesel engines. The smallest sizes, giving ¾ to 3 Brake Horse-Power (B.H.P.), are generally run only on petrol. For larger sizes, paraffin (or V.O. —tractor vaporising oil) may be used, owing to the greater importance of fuel cost. Petrol is in many ways a more satisfactory fuel than vaporising oil, and but for the artificial difference in cost caused by the heavy excise duty on petrol, there is no doubt that petrol would be the standard fuel for all small- and medium-sized farm engines. An increasing number of new engines of 5 B.H.P. or more are of the compression-ignition or " Diesel " type. The Diesel engine has advantages in fuel economy, and is thoroughly reliable; but it costs more than the petrol or paraffin type. The farmer should understand the inter-relation of initial cost, depreciation and fuel economy for the various types and sizes of engine, in order that the most suitable type for a given application may be chosen; but neither this aspect nor the working principles of the engines can be further discussed here.

Stationary internal combustion engines are used for driving barn machinery, water pumps and milking machines. Small portable engines are used for driving field machines such as elevators, while trailed machines such as mowers or binders may occasionally be powered by a small engine mounted on the machine. Many large combine harvesters and pick-up balers are driven by multi-cylinder engines incorporated in them. The greatest and most important use of internal combustion engines on farms is, however, as the power unit of the farm tractor. It seems unlikely that there will now be any great increase in the use of fixed engines on farms, owing to the increasing use of electric motors for all kinds of stationary work—especially the lighter jobs—and of tractors for all field work and such heavy stationary work as driving hammer mills or threshing machines.

Use of Tractors in British Farming. The modern farm tractor is a very versatile power unit. Equipped with pneumatic tyres, it can in most conditions haul loads along the highways or over the fields ; and in addition to providing power at the drawbar it can supply it at the belt pulley for such work as driving threshing machines, or at the power take-off in order to transmit steady power to such trailed machines as combine harvesters. Moreover, many farm machines have been re-designed to operate with tractors on the "unit" principle : i.e. with the implement mounted on the tractor in such a way that the tractor is an essential part of the equipment, and provides power through a hydraulic lift for raising and lowering the implement. It is clear that developments in this direction are still only in their infancy.

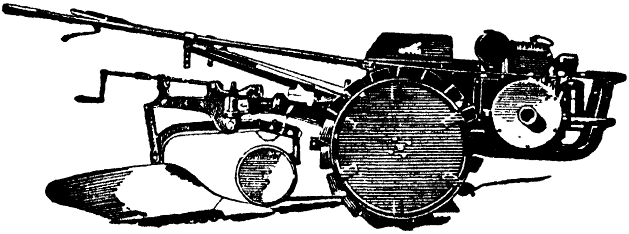
As the number of tractors employed on British farms has increased, so the range of work that they can profitably undertake has been continuously extended. There are, in fact, few jobs that a modern "all-purpose" tractor cannot do as well as or better than a team of horses, though it is not always economic to replace all horses by tractors. There are some jobs which horses do particularly well, especially light haulage work involving frequent stops ; and many farmers find it undesirable to attempt to do all such work by tractor power. Horses are particularly useful on farms where a high proportion of root crops is grown, and where carting in late autumn often presents a sizeable and difficult problem. The most economical use of the horse in modern farming is discussed in Chapter XIX. Modern tractor equipment, such as the hydraulic farmyard manure loader, makes it possible to eliminate manual work from an ever-increasing range of farm tasks.

THE PRINCIPAL TYPES OF TRACTORS

Tractors range in size from minute single-wheeled hoeing machines of about ¾ Brake Horse-Power (B.H.P.) up to giant tracklayers of 100 B.H.P. or so, while the majority of those used in Britain are medium-powered four-wheeled machines with engines developing about 25–50 B.H.P. and delivering 15–35 horse-power (H.P.) at the drawbar in good working conditions. There is no simple system of classification which is entirely satisfactory, but a general picture of the range of types and sizes is given by a grouping based mainly on the power of the engine. Farmers are more concerned with drawbar horse-power than with engine power as such, but comparable figures for drawbar horse-power are difficult to obtain in practice, owing to wide variations in operating conditions. Drawbar horse-power is readily calculated if the speed and drawbar pull (measured by means of a dynamometer) can be determined. It is given by the formula

$$\text{Drawbar H.P.} = \frac{\text{Speed (m.p.h.)} \times \text{drawbar pull (lb.)}}{375}.$$

A wheeled tractor of 25 B.H.P. may develop as much as 20 Drawbar H.P. in ideal conditions where the going is firm and the wheels can secure a good grip ; but in some conditions, such as on loose, deeply cultivated land, the same tractor may be incapable of exerting more than 10 Drawbar H.P. As is explained later, choice of suitable wheel or track equipment is almost as important as choosing the right size of tractor. A brief description of the main types of tractors is given below.



[*Trusty*]

FIG. 19.—A TWO-WHEELED MARKET GARDEN TRACTOR.

Market Garden Tractors. These are generally two-wheeled machines of up to about 8 B.H.P., but single-wheeled machines, single-track machines, very small tracklayers and very small three-wheeled and four-wheeled tractors may be included. These tractors are used mainly for hoeing and light cultivation, though some machines can deal successfully with a single-furrow plough. The two-wheeled machines have a single-cylinder engine ranging from a very small 2-stroke up to a robust 4-stroke giving 8–10 B.H.P. There is usually some adjustment of wheel track width, and sufficient ground clearance to permit straddling crops of moderate height. Methods of steering two-wheeled machines, type of gear-box, and ease of handling generally, vary between different makes. The usefulness of two-wheeled tractors depends largely on (*a*) mechanical reliability, (*b*) ease of handling and (*c*) the range and quality of the equipment available for use with the tractor, and the ease with which various units can be interchanged (Fig. 19).

Equipment includes ploughs of various types, including " one-way " ; general and row-crop cultivators ; drills ; hoes ; harrows ; rolls ; mowers ; spraying machines ; belt pulley ; and a bogie which converts the tractor into an articulated four-wheeled outfit suitable for light transport work with a two-wheeled trailer.

The single-wheel machines mentioned are used mainly for hoeing a single row. The very small tracklayers are useful in orchards and glasshouses, as well as in doing the usual types of market garden work.

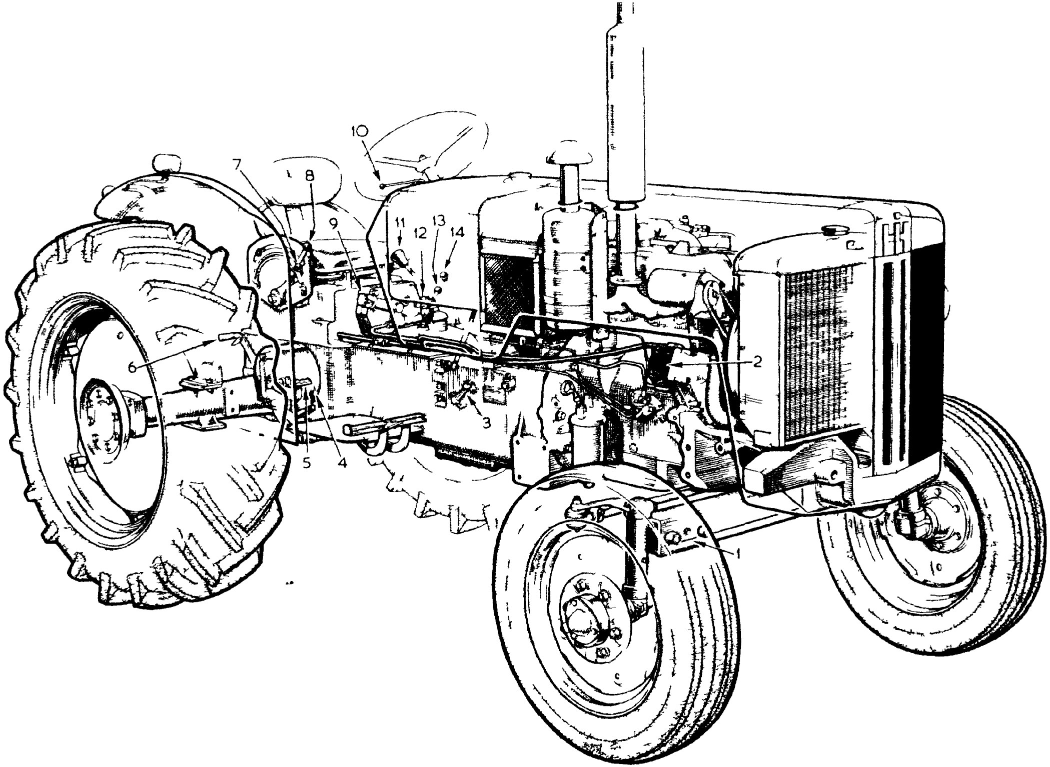
A three-wheeled outfit has the engine and transmission situated alongside or behind the driver and all the working tools in front. This type of machine is capable of very close work in narrow rows, and is very suitable for drilling and hoeing.

Small General-purpose Row-crop Tractors. These are generally four-wheeled and occasionally three-wheeled machines, specially adapted for work in growing crops, and with engines of about 12 to 25 B.H.P. No hard line can be drawn between the groups. On some small farms a machine of this size constitutes the main power unit for field work ; but as a rule this size of tractor is not considered powerful enough to deal with all types of work and is used as a supplement to a tractor or tractors of medium or large size (Fig. 20).

Essential features of the conventional type of row-crop tractor are (*a*) high ground clearance ; (*b*) wheels with narrow tyres or rims ; (*c*) wheels easily adjustable for various widths of row ; (*d*) a small turning circle ; and (*e*) fittings for the attachment and easy operation of various special row-crop tools. A power lift for the mounted tools and rear-wheel steering brakes are fast becoming standard fittings on row-crop tractors. While most of the small row-crop tractors used in Britain have four wheels, all adjustable, others achieve a very small turning circle and easier mounting of a front tool-bar by having a single front wheel.

Medium-powered Row-crop Tractors. This group includes three-wheeled and four-wheeled machines of 25–40 B.H.P., which are specially designed for row-crop work. This type is becoming very popular on British farms, being capable of doing all kinds of work undertaken by the medium-powered standard tractor, as well as many kinds of row-crop work. Tractors of this group should possess all the desirable row-crop features already mentioned, and should also be capable of heavy ploughing and cultivating. Recent developments with easily attached " unit-principle " implements, and the possibility of doing very heavy work in difficult conditions by fitting half-track devices, make some of the tractors of this class truly " all-purpose " machines. Further adaptability is secured in some machines of this group by arranging for easy conversion from four wheels to the three-wheeled or tricycle type. Tractors of this type may be equipped with forward tool-bars which are particularly efficient in the performance of such specialised work as covering potatoes.

Medium-powered " Standard " type Wheel Tractors. This group consists of tractors of 25–40 B.H.P. with no special provision for doing row-crop work. On some farms, where root and vegetable crops are not grown, the features provided by row-crop tractors are of little consequence, and the " standard " type may be used. Such tractors can be designed to have a shorter wheel-base and lower centre of gravity, and so can be made somewhat sturdier than the row-crop types. Very few machines of the standard type are now manufactured or are likely to be called for in future, since there are very few farms



KEY

1 Adjustable axle beam
2 Hydraulic pump
3 P t o speed selector
4 Disc brake (one each side)
5 Differential lock pedal
6 Hand brake lever
7 Draught control
8 Position control
9 Isolating valve
10 Engine speed control
11 Gear lever
12 Flow rate control
13 P t o engagement lever
14 High and low range gear selector

Fig. 90 — International Harvester B—414 medium-power tractor

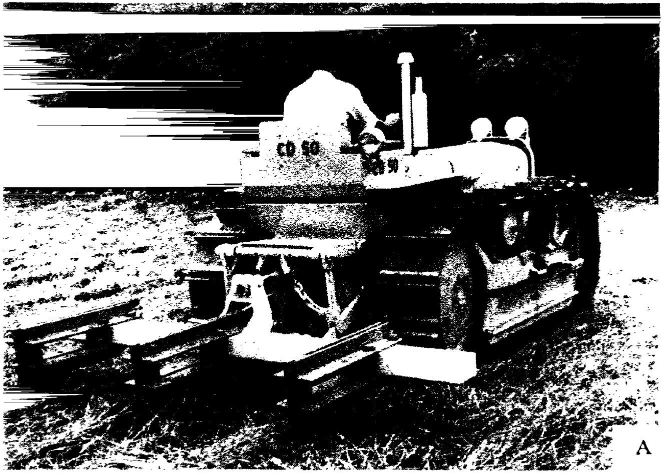
on which row crop features are not of sufficient value to justify a slight extra manufacturing cost.

Medium-powered Tracklayers. This group includes tractors of 40 to 50 B.H.P. on tracks, corresponding drawbar horse-powers being about 30 to 40. On certain types of land such as steep hillsides, on heavy land that requires deep work, and fenland and other similar types where very deep cultivations are practised, the use of track-laying machines is essential for efficient working. Such machines can secure good adhesion and transmit heavy pulls in conditions which are almost or quite impossible for wheeled tractors. The only likely competitors in this type of work are half-track conversions, which are cheaper to buy and to repair. The main disadvantages of full-track machines are the high initial cost, the cost of repairs and renewals, and the fact that the tracklayer is not, in the conventional form, suitable for running along hard roads.

High-powered Wheeled Tractors. Wheeled tractors of above 50 B.H.P., generally of the standard four-wheeled type, are used on some large farms where conditions do not require the use of tracklayers. In such conditions, one man driving a large wheeled machine may be more economic than two driving smaller tractors, provided that suitable implements for the bigger type are available. Heavy tractors equipped with pneumatic-tyred wheels are very suitable for use with travelling threshing machines in hilly country, where lighter tractors frequently get into difficulty with a standard-size threshing machine (Plate V).

Large Tracklayers. This group consists of tracklayers of 55 B.H.P. or more. Almost all tractors of this type are now equipped with Diesel engines. The chief users of large tracklayers are contractors, who undertake such heavy work as very deep ploughing and cultivating, subsoiling, mole-draining, bull-dozing, and so on. These machines, and also the equipment for use with them, are extremely expensive ; and their purchase can only be justified where the tractors are fully employed (Plate III).

The Working Capacity of Tractors. The best indication of a tractor's power or capacity for work is its drawbar horse-power. In the United States it is usual to describe tractors according to the number of plough furrows that can be pulled in medium land at a speed of 3 m.p.h. In such " average " conditions approximately 5 drawbar horse-power is required to pull a furrow about 10 in. wide and 6 in. deep, so that a tractor capable of exerting 15 drawbar horse-power in normal conditions is called a " 3-plough " tractor. In choosing a tractor the farmer should have a clear picture of what various machines will do on his own land and with the equipment that will be available. Few things are more annoying to a farmer than to send a tractor and implements to do a job and find that power unit and implement are not suited to one another or to the work in hand. While small tractors can often tackle heavy work if equipped with tools that they can manage, they may fail completely if the tools are too wide. On the other hand, a big surplus of power is wasteful owing to the higher running costs.



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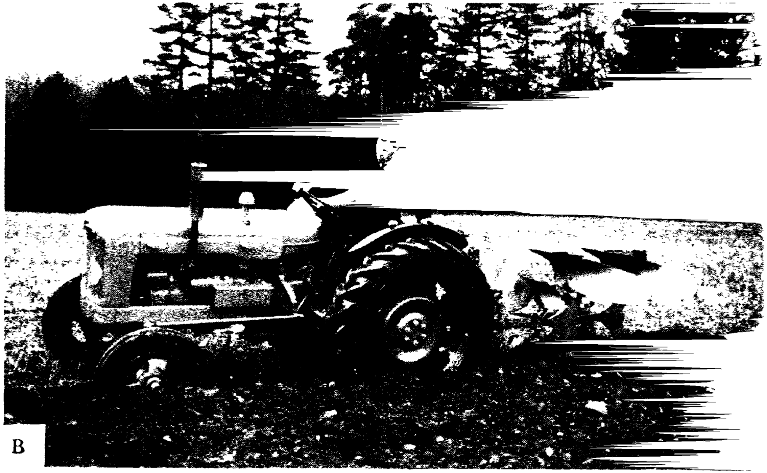

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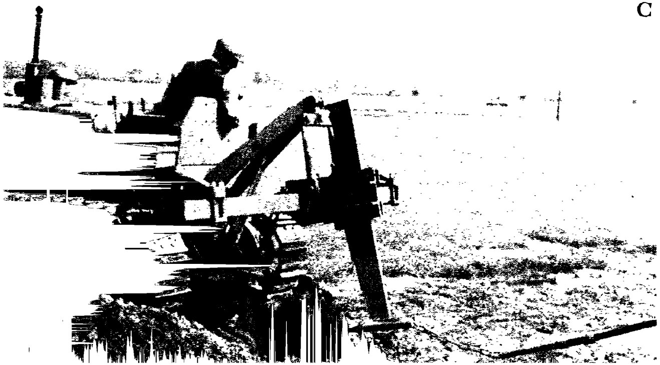


PLATE III

A. Track-laying Tractor fitted with three Sub-soiling Tines

B. High-powered Tractor with two-furrow reversible Plough

C. Tractor-mounted Mole Drainer being used to pull in Water Piping

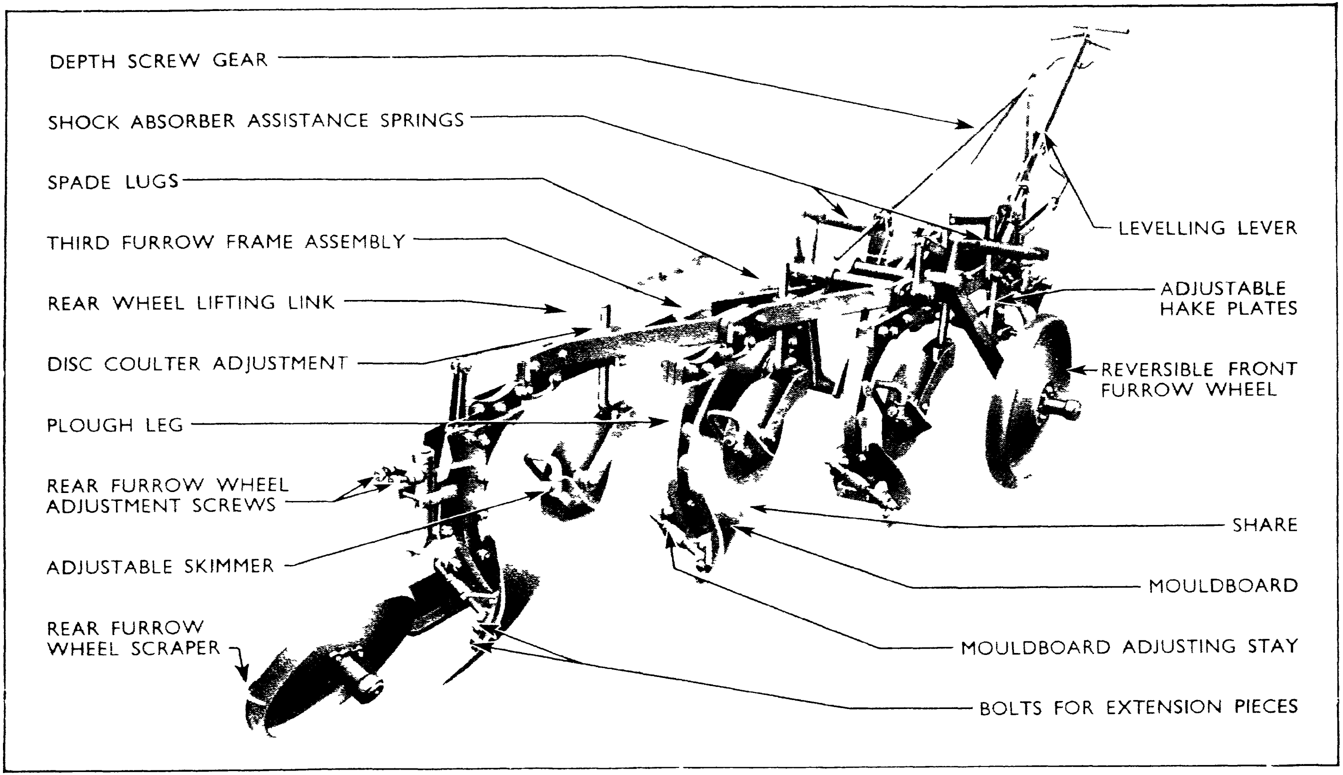

DEPTH SCREW GEAR
SHOCK ABSORBER ASSISTANCE SPRINGS
SPADE LUGS
THIRD FURROW FRAME ASSEMBLY
REAR WHEEL LIFTING LINK
DISC COULTER ADJUSTMENT
PLOUGH LEG
REAR FURROW WHEEL ADJUSTMENT SCREWS
ADJUSTABLE SKIMMER
REAR FURROW WHEEL SCRAPER
LEVELLING LEVER
ADJUSTABLE HAKE PLATES
REVERSIBLE FRONT FURROW WHEEL
SHARE
MOULDBOARD
MOULDBOARD ADJUSTING STAY
BOLTS FOR EXTENSION PIECES

PLATE IV COMPONENTS OF THREE FURROW PLOUGH

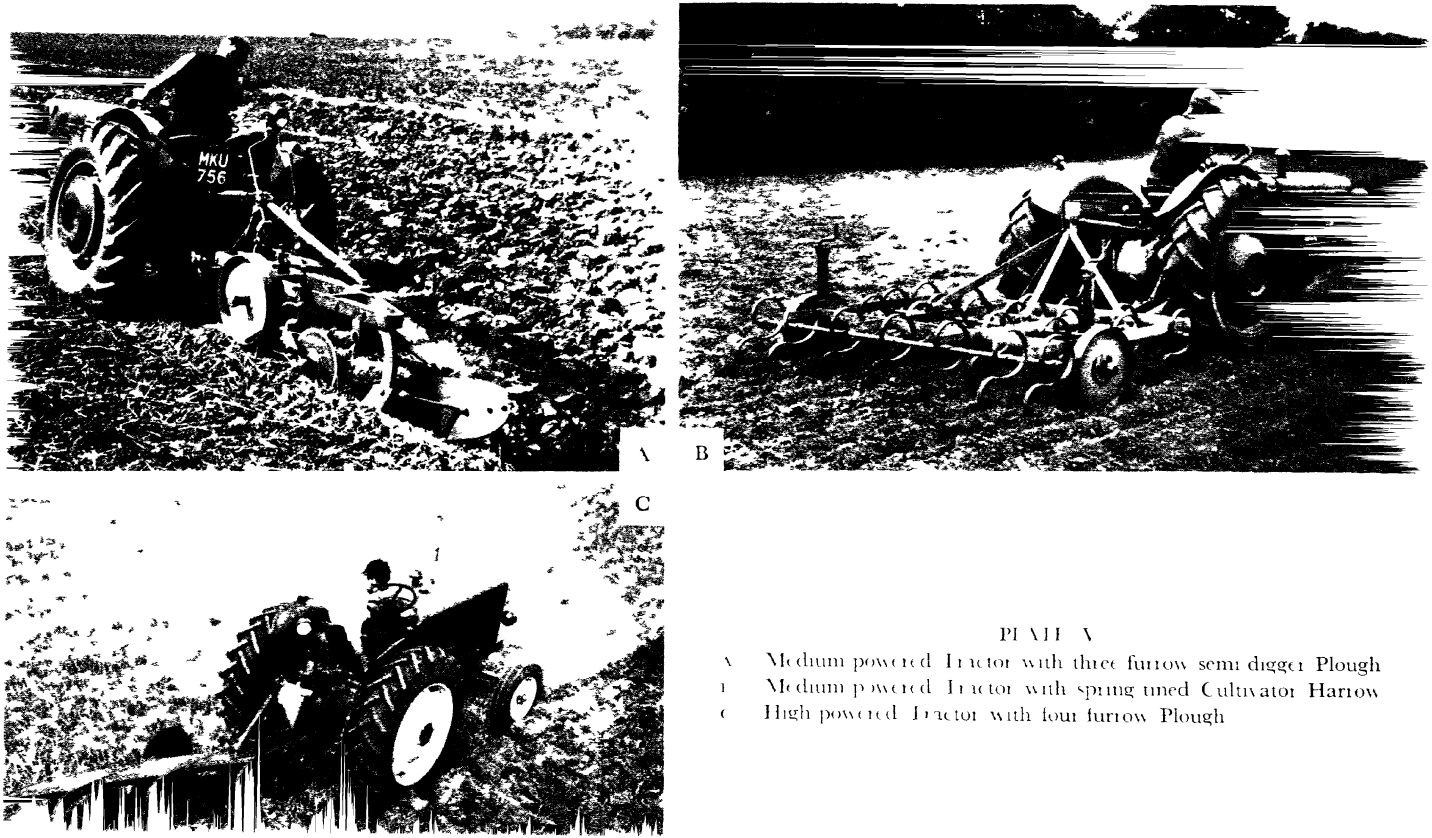
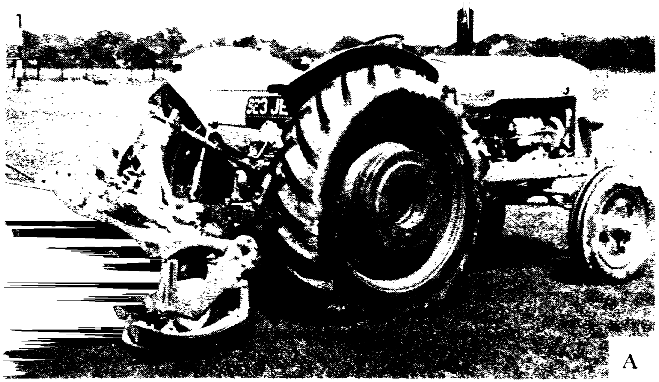


PLATE V

A Medium powered Tractor with three furrow semi digger Plough
B Medium powered Tractor with spring tined Cultivator Harrow
C High powered Tractor with four furrow Plough



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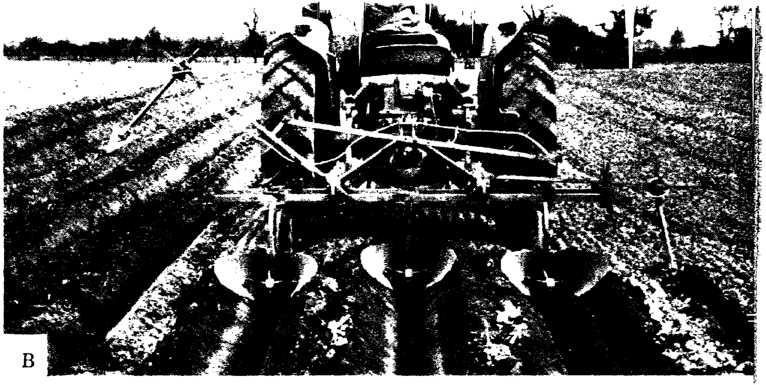

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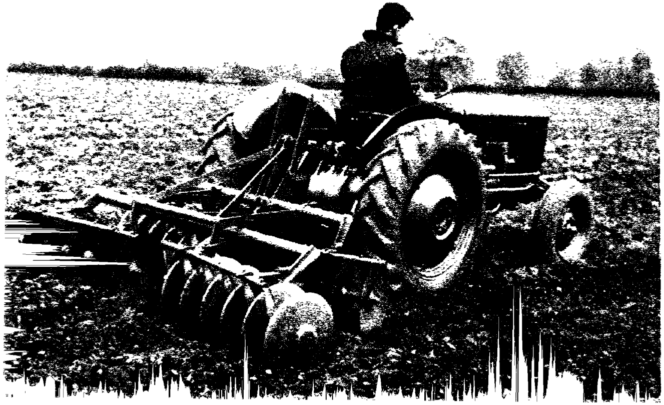
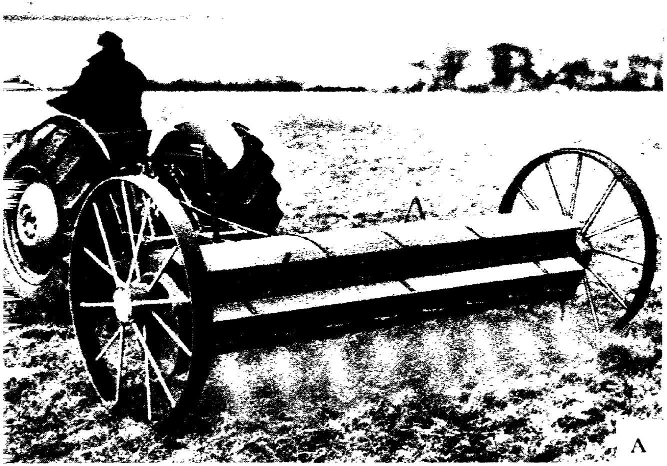


PLATE VI

A. Rotary Cultivator showing the hoe-type Blades
B. Ridging Bodies on Rear Tool Bar
C. Mounted Disc Harrows



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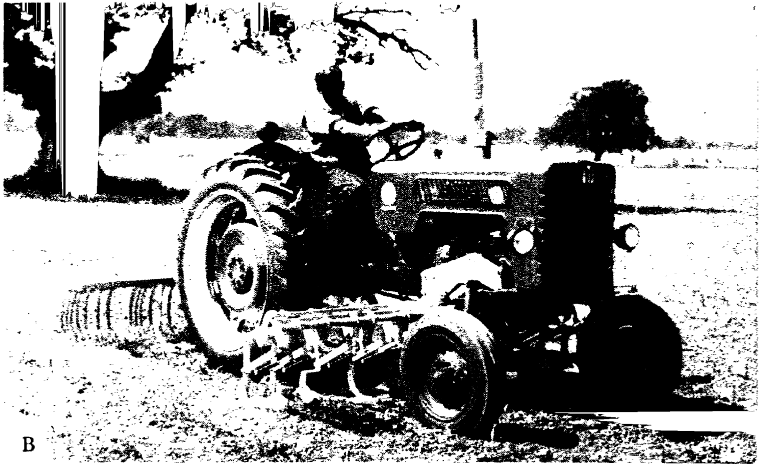

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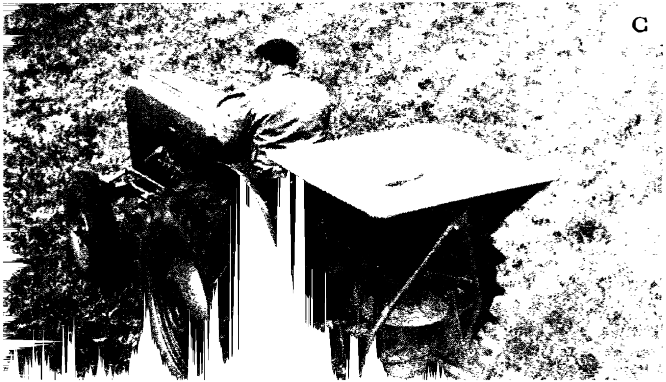

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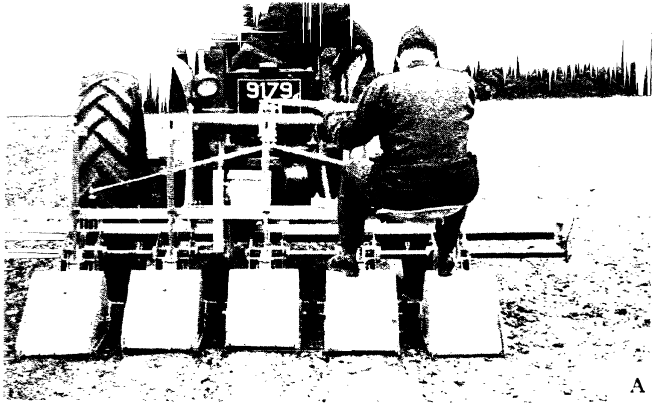
PLATE VII

A. Fertiliser Distributor—plates and flicker type

B. Mid-mounted Hoeing Tool Bar and rear-mounted Weeder

C. Mounted Spinner-Broadcaster for Fertilisers



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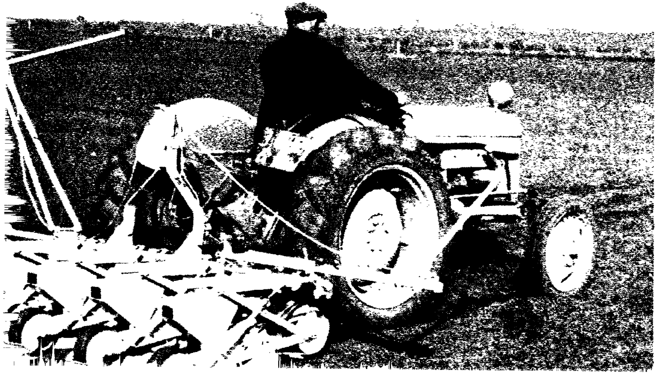

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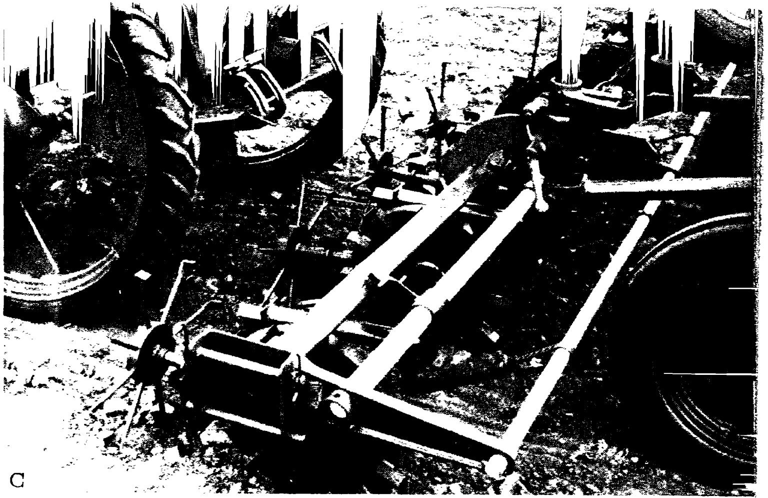


PLATE VIII

A. Set of inter-row Rotary Hoes

B. Seeder Units

C. Down-the-row Thinners (rotary) on rear-engined Row-crop Tractor

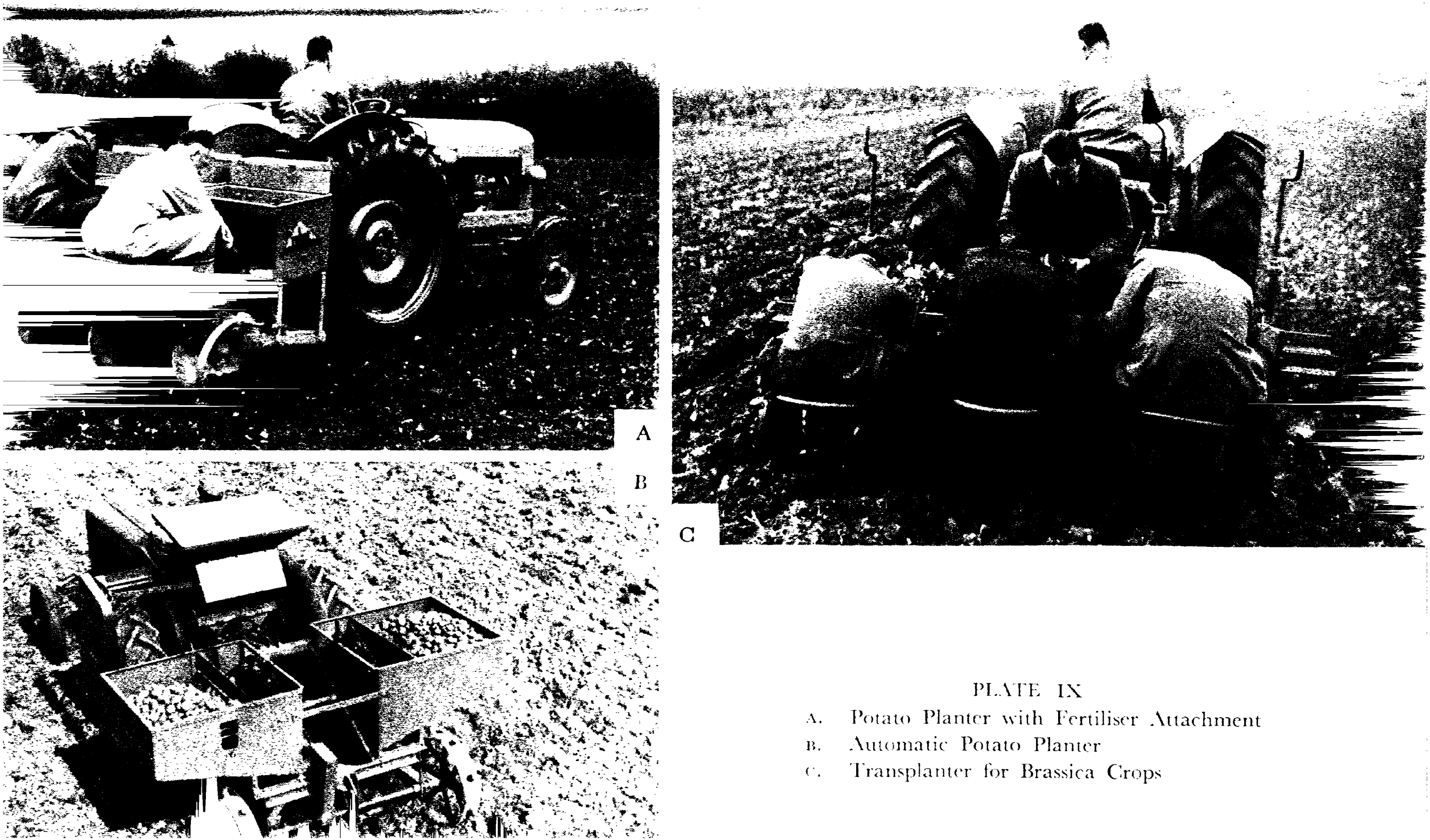
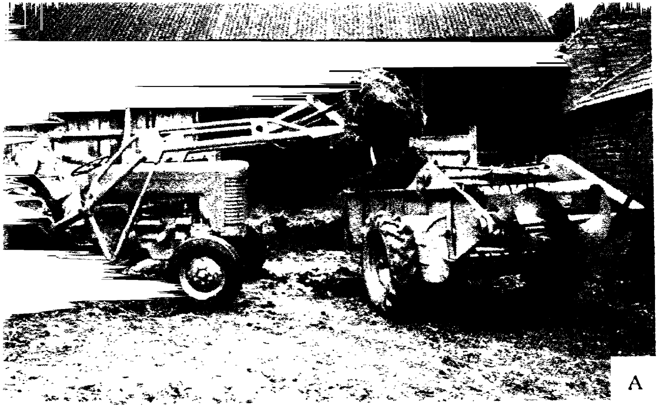


PLATE IX

A. Potato Planter with Fertiliser Attachment
B. Automatic Potato Planter
C. Transplanter for Brassica Crops



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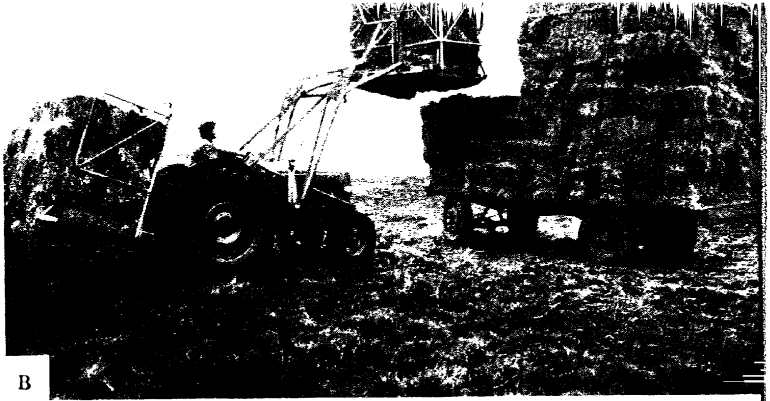

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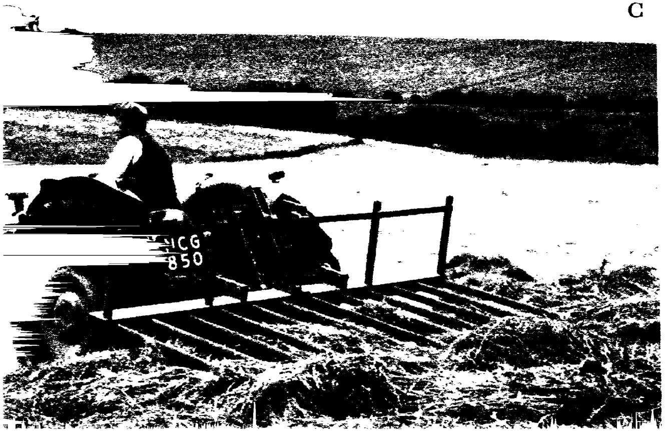


C

PLATE X

A. Fore-end Leader filling a Manure Spreader

B. Fore-and-aft Bale Carrier

C. Rear-mounted Buck-rake

If it is known how many plough furrows a tractor will normally pull on a certain type of land, a fair estimate may be made of the width of other standard implements that it should handle. Thus, a tractor capable of pulling three 10-in. furrows 7 in. deep can generally handle three times the width of cultivator or disc harrow (7 ft. 6 in.), six times the width of heavy harrow (15 ft.) and five times the width of drill (12 ft.).

THE ECONOMICS OF CHOOSING AND USING TRACTORS

Cost of Operation. The cost of operating a tractor, like many other costs connected with farming, varies considerably from farm to farm. Important factors influencing cost, in addition to the obvious ones relating to size and type of machine, are the number of days worked annually, the types of work performed, and the care the tractor receives in maintenance and operation. Annual use of tractors varies from a few hundred hours on small farms to 2,000 hours or more on large light-land farms where field work can be carried on throughout the year. Naturally, a high level of annual use generally results in a low hourly cost, owing to the fact that some of the overhead charges are little affected by the amount of use. While due regard may be paid to a low hourly cost, neither this nor a low total annual cost necessarily gives a measure of efficiency, since true efficiency can be arrived at only if the results of the work done are taken into account. The average cost of operating a medium-powered diesel tractor on a farm where 1,000 hours of work per annum are done may be of the order of 8*s.* 6*d.* per hour, of which the labour cost amounts to 4*s.* 6*d.* while fuel and lubricants account for 1*s.* 3*d.* and depreciation and repairs for 2*s.* 6*d.* per hour. The balance is made up of licence, insurance and sundries.

Choice of a Tractor. The choice of a tractor requires careful study. To be over-powered is wasteful, while to be under-powered may be disastrous. The most important work for the average British tractor is still ploughing and heavy cultivations, and where only one tractor is used it must be able to do this work in the limited time available. There is much to be said in favour of the medium-powered types of tractor, which are capable of making a good job of such heavy work, yet are not too heavy and wasteful to do the countless other lighter jobs that are called for on a reasonably mechanised farm today.

The medium-sized tractor which is to be generally useful for all types of work may need more than one type of wheel equipment. Pneumatic tyres, steel wheels, and a narrow steel rim for row-crop work, may be conveniently bolted to a common wheel centre. Wheel track widths should be easily adjustable if the tractor is needed to do row-crop work. The " all-purpose " tractor is applicable to a still wider range of work if it can be fitted with half-track units in place of the rear wheels.

For medium-powered tractors there is usually a choice between petrol, paraffin and Diesel engines. The tax charged on petrol rules it out as an economical fuel for any but the smallest tractors, though it would certainly be generally used if it were subject to the same smaller tax as tractor vaporising oil. The initial cost of a Diesel engine is higher than that of a paraffin engine, but the fuel cost is less. On farms where the tractor does about 750 to 1,000 hours of work annually and the tractors are efficiently operated and maintained, there is usually little to choose in total operating cost between Diesel and paraffin types.

Economic Loading. One of the most important factors concerned with economic operation of a tractor is the choice of implements suited to the tractor's capacity. A tractor works most economically when provided with a load round about 75 per cent of its maximum power capacity. Light loads not only result in poor fuel economy, but may also lead to excessive wear through dilution of the lubricating oil, which increases when the engine runs too cold. In some instances it is possible to achieve both speed and economy of operation by hitching together two or more implements in tandem. For example, where a tractor is capable of pulling a drill and a set of harrows together, it is worth while to devise a hitch so that both operations may be done in one journey across the field.

Working Speeds. The most economic operating speed depends partly on the job and partly on the wheel or track equipment. Tracks and wheels with spade lugs are not designed for fast work, and the maximum drawbar power is developed at speeds in the region of 3 m.p.h. Pneumatic-tyred tractors, on the other hand, which cannot exert such high drawbar pulls, need to go faster in order to develop their maximum drawbar power. Some rubber-tyred tractors develop their maximum drawbar power at speeds of about 5–6 m.p.h. Most modern tractors are equipped with one very high gear giving a road speed of 10–20 m.p.h.; but this gear cannot often be used for field work.

Optimum speed is, of course, much influenced by the implement. With ploughs, where draught increases with speed, there is no advantage in high speed except where light-weight rubber-tyred tractors are used. In this instance, plough bodies specially designed for high-speed work are required. Most cultivation implements, drills and manure distributors work best at fairly low speeds, while hoeing cannot be efficiently done at above about 3 m.p.h. A trailer mower sometimes works better at 4 m.p.h. than at lower speeds, and this may be achieved economically by running in high gear with the engine throttled down. The binder needs a speed of 3–4 m.p.h., while combine harvesters need a range from about 1 to 4 m.p.h. to suit different crop conditions. Hay sweeping is one of the few field operations calling for a fairly high speed, 6 m.p.h. or thereabouts often being desirable. At the other end of the scale, such a machine as a transplanter requires speeds of as little as ¼ m.p.h. Thus, an all-purpose tractor requires a wide range of gears, with several fairly close together at 2 to 4½ m.p.h., and a governor that is effective over a wide range of engine speeds.

Tractor Maintenance. Tractors and their equipment are now of such prime importance on British farms that systematic attention to care and maintenance is essential. All tractor manufacturers provide a handbook which gives detailed instructions on such matters as adjustments, lubrication and minor running repairs. These books are of interest to intelligent drivers, and full use should be made of the information contained in them.

Adequate maintenance of tractors and implements is facilitated if a fuel and spares trailer is provided, so that everything required for everyday use is ready to hand, even when the tractor is working a long way from home.

At home there should be a tractor shed, and a workshop where the tools necessary for running a farm can always be found. Farmers who grew up with horses and have more accommodation for horses than they will ever need again, often fail to give much thought to housing and maintaining the machines which have replaced the working animals.

ELECTRICITY ON THE FARM

The use of electricity on farms in Britain has steadily increased in recent years, and with much attention now being devoted to electrification of rural areas it may be expected that progress will be much more rapid in the future. In addition to farms provided with a public electricity service, there are many which obtain electricity for lighting by means of small generators driven by an internal combustion engine. The modern Diesel-electric generator is an efficient unit, and is worth consideration on isolated farms where there is no possibility of a public service.

The supply of electricity to farmyard, farmhouse and cottage is of great importance to the well-being of country people generally, supply to the houses being even more urgent than that to the farm buildings. Much daily drudgery is removed when lighting, heating, water-pumping, washing and ironing can be done by electricity. In short, electricity is probably more important than anything else in raising the standard of living of country people, and so encouraging men and women to live and work on the land.

The main applications of electricity on farms are concerned with quite orthodox lighting, heating and power devices. The advantages of electric lighting in farm buildings, especially where dairying is carried on, are immense. Heating applications include sterilisers for dairy utensils, where the cleanliness and saving of labour often more than offset any extra cost ; brooder heaters, where ease of control and safety are important factors ; grain drying, where ease of control and efficiency of utilisation of the heat to some extent offset extra fuel costs ; and incubators, where thermostatic control leads to fuel economy, as well as ease of regulation. The special advantages of electrical methods often outweigh considerations based on the relative cost of heat from electrical and alternative sources, and it is likely that heating applications of electricity on farms will extend considerably.

The electric motor has many advantages over other stationary power units for small or moderately small power requirements, and its use on farms is steadily increasing. The standard industrial

" protected " types are quite suitable for most farm purposes. The larger motors require special devices to reduce the starting current, and occasionally the more expensive slip-ring type has to be used for large power applications. Typical tasks, with the size of motor used, are as follows: milking (1–2 H.P.); cooling (¾–3 H.P.); grinding (3–15 H.P.); threshing (12–20 H.P.); and water pumping (1–3 H.P.). For large power applications such as threshing and driving a large hammer mill the farm tractor is often just the right size, and where demands for such work do not interfere unduly with essential field work it is often better to use the tractor than to install a large electric motor. A characteristic of electric power of which good use can be made is the ease with which automatic control can be arranged. For example, when a pressure tank is used in a water supply, pressure control may be employed to switch the motor on and off; and the motor used in a farm grinding installation may be switched off after a certain time, or when the flow of grain to the mill ceases. Other advantages are the ease of starting, reliability and very small amount of time required for maintenance.

While the major uses of electricity on farms are concerned with straightforward heating, lighting or power applications, there are a few special uses where characteristics peculiar to an electrical device are employed. Examples of such uses are the electric fence, by means of which a sharp but harmless electric shock is used for fencing against livestock; the electric insect trap, which destroys flies alighting on a wire mesh window screen by electrocuting them; and the treatment of livestock by ultra-violet and infra-red radiation. It may be expected that such special uses of electricity will be multiplied as electric power becomes more generally available to farms.

Electric Fences. Most British electric fence units are battery-operated and are powered by a 6-volt accumulator of the type used in cars. A battery of 20 amp.-hours capacity will electrify up to 15 miles of fence and will last for about 20 days of continuous use. Mains-operated fences are widely used in some countries, e.g. Denmark, and are becoming popular here; they are safe and efficient if properly designed and tested control units are employed.

Chief points to observe in operating electric fences are:

1. Wire spacing. One wire at 24–30 in. is satisfactory for cattle and horses; sheep and pigs need two wires at 12 and 18 in. 2. Insulation. Proper insulators must be used, and the fence wire must be kept clear of the crop and of trees, etc. 3. The unit must have an effective " earth " connection. 4. The stock must be trained to respect the fence, since it is fear rather than the wire which keeps them back. When the fence is first erected the animals must be allowed to approach it quietly. A good way of tempting them to try its effect is to place some food just beyond it.

Chapter V

TILLAGE AND TILLAGE IMPLEMENTS

THE OBJECTS AND PRINCIPLES OF TILLAGE

TILLAGE is the practice of working the soil with implements in order to provide conditions favourable to the growth of crops. It is based partly on a knowledge of soil science, but possibly to a larger extent on an acquired skill which comes by practice and experience. It has been truly said that the cultivation of the soil remains today more an art than a science.

Not only do different soils vary greatly in their reactions to implements ; but an individual soil varies from day to day according to such factors as its moisture content (which is easily recorded) and the exact sequence of moisture changes in individual clods (which is almost impossible to record accurately). While it is not possible in the present state of knowledge to lay down any hard-and-fast rules about tillage, there are certain fundamental principles which every student of farming must understand. In general, " light " or sandy soils are easy to work, and can be tilled at almost any time of the year, while " heavy " or clay soils are more difficult to manipulate and can be satisfactorily tilled only at certain seasons, when the moisture content and weather are suitable. The effects of natural agencies on soils is a matter of great importance to the farmer, since it is only by working with these natural agencies that the most economic methods of working can be achieved. For example, frost is an agency of vast consequence in the farming of heavy land. When such land is ploughed early in winter it often has a texture similar to that of plasticine. When it is well frozen, however, the water in it expands and splits the soil into planes of partition which later assist in the formation of soil " crumbs " or tilth. As the soil dries out in spring the clods break down, and if worked by implements at the right time a very fine tilth can be secured on land which a few months earlier seemed to defy any attempt to secure a seed-bed. If, however, the farmer is in too great a hurry and a soil which has been frozen and is lying well is cultivated too soon, i.e. when still too wet, all the advantage gained by weathering can rapidly be lost. Even very heavy rain coming after frost may sometimes so " puddle " the land as to destroy the crumb structure and leave in its place a nasty sticky clay which is very difficult to handle. There are, of course, all gradations of soils between the heaviest clays and extremely light soils ; and some which behave as light soils for most of the year have just sufficient fine particles to render their cultivation a tricky job.

The other great ameliorative weathering agency—even more important than frost—is alternate wetting and drying of the land. Tillage can make use of this effect in many ways. A furrow or clod of clay soil, when thoroughly dried, contracts considerably and becomes hard, almost like concrete. When re-wetting takes place expansion occurs, and the outer layers of soil become split off into small particles. The process is repeated when re-drying and re-wetting occur, so that in time a tilth, or layer of fine friable soil, is formed.

These two examples should make it clear that the farmer, especially he who decides to farm on heavy land, cannot possibly use his tillage implements to best advantage without a knowledge of what is likely to happen to the soil in changing weather conditions.

The main objects of tillage may be conveniently discussed under the following headings :

1. The production of a suitable " tilth " or soil structure ;
2. The control of soil moisture, aeration and temperature ;
3. The destruction of weeds ;
4. The destruction or control of soil pests ;
5. Burying or clearing rubbish, and incorporation of manures in the soil.

1. The Production of Tilth. When soils are left uncultivated for long periods, the soil particles become stuck together, the air spaces become small, and the friable structure of the soil is lost. In such conditions it is impossible to sow seeds satisfactorily, and tillage implements must first be used to restore a " tilth " favourable to the crop. The tilth required and the implements used vary according to the type of crop, some crops needing a fine, firm seed-bed, while others do best where there are clods, and only sufficient fine mould to ensure covering the seeds.

In the preparation of seed-beds, ploughing is usually, but not always, the first tillage operation. The plough cuts the soil into rectangular slices or furrows and turns them over so that the rubbish is buried and the soil surface is exposed in a rough condition to the weather. There may then be a considerable interval before the next operation, but later on the land is generally cultivated by one or more of the tined implements, by disc harrows, by rolls, or other tackle described later. The farmer must choose those implements which will give him the desired tilth with a minimum of effort. Very often it will be necessary to try out various implements in the field before a satisfactory effect is produced, for it is not always possible to forecast in advance which of the cultivation implements will work best.

2. The Control of Soil Moisture, Aeration and Temperature. Tillage is concerned in many respects with adjustment of soil moisture content to the needs of the crop. For example, the land may be deeply cultivated and left rough at the surface in autumn, so that winter rains may easily penetrate, and the surplus pass down to the drains. On some soils, if the surface is left too fine and smooth in autumn, the winter rains will cause the soil to " run together " on the surface and prevent the percolation of water. When it is necessary to produce an early seed-bed on a soil that lies wet in spring, a rough surface must first be produced, generally by the plough, in order to induce a partial drying.

On the other hand, at seeding time in spring it is often necessary to produce at the surface a finely divided crumb structure which will act like a sponge and keep any rain that falls in the upper layers, so that the seed will germinate. Consolidation of the land sometimes has important effects on movement of water through the capillary spaces in the soil. For example, if the soil is very moist below and has a dry " fluffy " layer on top, rolling will cause moisture from below to pass into the surface layer.

Aeration of the soil, like many other effects of tillage, is still not perfectly understood. It is well known that oxygen is required for the germination of seeds, the respiration of plant root systems and the activity of beneficial aerobic bacteria in the soil. The few scientific experiments recorded, however, suggest that it is only rarely, as when the soil is waterlogged, that lack of aeration as such becomes a limiting factor in plant growth in normal farming conditions.

Soil temperature is closely bound up with soil moisture. Soils which are wet in spring are cold because water absorbs much heat in warming up, while large amounts of heat are absorbed in the evaporation of moisture from the soil.

3. **The Destruction of Weeds.** Weed destruction is one of the most important of all the objects of tillage, and the methods employed vary widely according to the type and condition of both soil and weeds. Annual weeds can be killed by completely burying them, or by dragging them out and leaving the roots exposed in dry weather. Most weeds are quite easily destroyed in the seedling stage, and one further object of tillage is to create soil conditions which will make weed seeds germinate, so that the seedlings may be destroyed by subsequent cultivations before the crop is sown. On some light soils where annual weeds are troublesome, farmers make a regular habit of killing successive crops of weed seedlings before sowing their roots in spring. One of the objects of autumn cleaning, referred to again later, is to germinate the seeds of such weeds as speedwells, chickweed, wild oats, black-grass, poppy, etc. There are, unfortunately, a few weed seeds, such as those of corn buttercup, fat hen and knot-grass, which do not readily germinate till late in the year.

Some perennial weeds, such as couch grass, occasionally need to be combated by special methods, as described in the section dealing with combined tillage operations for cleaning (see p. 135).

Many experiments on the inter-cultivation of root crops show that the benefits of tillage between the rows are almost entirely due to weed control. This has been proved by tests in which weed control has been achieved by cutting at ground level, without stirring the soil in any way. Other experiments have shown that additional hoeings beyond the amount required to control weeds may result in lower crop yields, because of damage to roots of the crop close to the surface.

Other aspects of weed control are dealt with in Chapter VIII, and in Appendix VI.

4. **The Control of Soil Pests.** While tillages sometimes react directly on soil pests by exposing them to the attacks of birds, by

drying them out, or by crushing them, they are more generally employed to resist pest attacks indirectly, by improving conditions for plant growth. For example, when wheat growing on a " fluffy " soil is attacked by wireworms or by the larvæ of the wheat bulb fly, firming the soil by the use of a roll may often be effective in minimising the damage. The improvement produced in such circumstances is due more to the better conditions provided for the plant roots than to any direct effect on the insects themselves, though thorough consolidation may to some extent restrict the insects' activity.

5. **Burying Rubbish and Incorporating Manures in the Soil.** Crop remains and farmyard manure must be buried in order that the organic matter may be incorporated in the soil, and that the surface of the land may be cleared of rubbish which would interfere with the action of drills and hoes. The plough is normally used for burying rubbish, and one of the chief requirements of good ploughing for British conditions is that all vegetation should be effectively covered by soil. It may be observed, however, that there are important " dry-farming " areas in other parts of the world, notably in North America, where a primary aim in cultivation is to prevent wind erosion by leaving as much rubbish as possible anchored in the soil but sticking out from the surface. In the " dry-farming " areas of the United States and Canada the plough which buries rubbish completely has been found worse than useless, and disc cultivators, sub-surface cultivators, and other special implements are now used in those areas. It has been argued from this, though without much justification, that ploughs which bury vegetation completely are quite unnecessary and should everywhere be scrapped. It is fairly certain that the adoption of such tillage tactics on British farms would rapidly result in weeds getting out of hand.

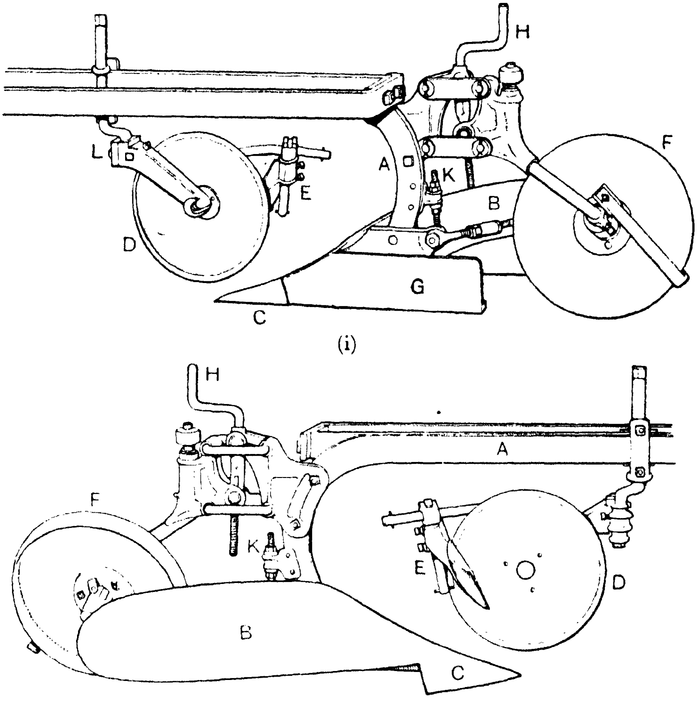
Cultivators and harrows are often used for mixing fertilisers with the soil before crops are sown. In other instances drills and planting machines are so designed as to distribute the fertiliser in bands alongside the rows of the crop. Fertiliser placement is further discussed in connection with manure distributors and combine drills.

PLOUGHS AND PLOUGHING

The plough separates a layer of soil from the underlying subsoil and inverts it, so that any vegetation or manure present on the surface is buried and soil from below is exposed to the action of weathering agents and to other implements. The ploughed land is laid up in parallel furrow slices, the type of slice depending on the shape of the plough body and on the nature of the soil. Modern ploughs are the result of a process of gradual development extending over thousands of years.

The Plough. Ploughs may be broadly divided into two main types, viz. the lea plough (Fig. 21) and the digger plough (Fig. 23). The chief difference between the two types is that the lea plough turns long, unbroken furrow slices while the digger has a tendency to pulverise the soil.

The *coulter*, which makes the vertical cut, is fastened to the plough beam. The other soil-working parts, viz. the share, which makes the horizontal cut; the *mould-board*, which turns the furrow; the landside, which slides against the furrow wall; and the slade or sole, which slides along the furrow bottom, are all attached to the plough frame which is a casting of complicated shape fastened beneath the beam.



(i)

(ii)

FIG. 21.—THE PRINCIPAL PARTS OF A TRACTOR PLOUGH BODY (LEA TYPE). (i) LAND SIDE. (ii) FURROW SIDE.

A, beam. B, mould-board. C, share. D, disc coulter. E, skim coulter. F, rear wheel. G, landside. H, rear wheel adjustment. K, pitch adjustment. L, coulter tilting adjustment.

Coulters are of three main types, viz. knife, disc and skim. The knife coulter is the normal type on horse ploughs, but on tractor ploughs the disc type, which can work in difficult conditions without blocking, is used on all except a few special implements designed for very deep work. The skim coulter is used to assist in the complete burying of manure, rubbish or crop remains. It acts as a miniature digger plough, and is fastened to the plough beam just behind the disc coulter or just in front of the knife coulter. On rare occasions disc, skimmer and knife coulters may be used simultaneously. The combined disc and skimmer has become a very popular fitting on tractor ploughs.

The *share* (Fig. 22) fits over the front or " nose " of the frame.

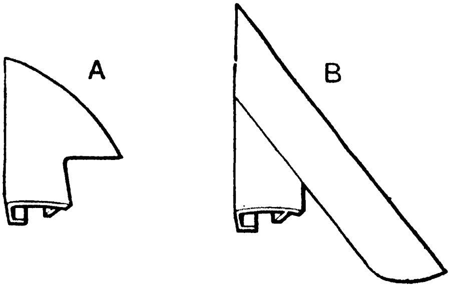


FIG. 22.—FORMS OF PLOUGH SHARES.
A, normal type. B, for skimming stubbles. C, pointed share for stony land.

On the lea plough it has a definite " neck " which has the effect of placing the cutting edge well ahead of the mould-board. The " lead " thus obtained assists in keeping the furrow slice unbroken, enabling it to pass gently from share to mould-board. The digger plough, on the other hand, has the cutting edge of the share close to the mould-board and often almost at right angles to the line of draught. Most shares on horse ploughs, and also on the smaller tractor ploughs, are made of cast iron which is chilled on the under face of the cutting edge. Chilling of this face makes it harder than the top ; and in use the lower side wears more slowly, giving a self-sharpening effect. If chilled cast-iron shares do become blunt when only slightly worn they may be improved by grinding the upper edge.

On some ploughs the nose over which the share-box fits is carried at the forward end of a lever which pivots in the frame casting. This type of plough body is called the " lever-neck ", and it has the advantage of providing easy adjustment of the pitch of the share. In districts where rocks are often encountered in ploughing, a popular type of share is the " bar-point ". This consists of a steel bar which passes through the frame and forms the point of the share. When the bar-point has become blunted the bar may be turned over or reversed end for end. Later, it may be sharpened by heating, hammering out to a chisel point, and hardening.

The mould-board is attached to the frame by bolts with countersunk heads. The lea type, which may be up to about 4 ft. 6 in. long, is convex from top to bottom throughout its length with a gradual twist which turns the furrow slice very slowly and finally presses it against the previous one. The digger type of mould-board is much shorter and has an abrupt concave curvature which bends the furrow slice sharply on itself and throws it aside. There are many intermediate general-purpose bodies between the extreme lea and digger types. Digger and semi-digger bodies are becoming increasingly popular for general work. They have the advantage that deep work can easily be done when required, whereas with lea ploughs depth of work is very limited. Even where land is being set up for the winter it is generally found that the rough clods left by a digger body weather as easily as the unbroken furrow slices left by a lea type.

The *landside* takes the side thrust caused by the pressure of the furrow slice on the mould-board. It is often in one piece with the slade, which supports the weight of the plough. On wheeled ploughs such as tractor ploughs, where these thrusts can be taken on suitably disposed wheels, the landside and slade can be almost or entirely dispensed with.

Tractor Ploughs. The common type of trailed tractor plough has a number of parallel beams, each carrying a plough body of the usual type, and mounted on three wheels. The two large wheels, i.e. the furrow wheel and the land wheel, are carried on cranked axles, and the depth of work is controlled by screws or levers which regulate the rotation of the cranks. There is normally a rear wheel which runs in the furrow, and the hitch to the tractor is by a triangular framework which is flexible in a vertical direction and rigid (but adjustable) horizontally. Some single- and two-furrow ploughs have no rear wheel and a " semi-floating " hitch, so that the plough is balanced on its two wheels. The principal parts of a tractor plough body are shown in Fig. 21 and Plate IV.

With the exception of a few very light market-garden implements, all trailed tractor ploughs are provided with some form of self-lift mechanism for raising them out of work. The normal method is to have a clutch carried on the land wheel axle, such that when a cord is pulled the clutch is engaged, and rotation of the wheel causes the cranked axle to rotate solid with it. The furrow wheel, being interconnected, moves in a similar way. When the axles have rotated until the wheel centres are almost directly beneath the supporting brackets the lifting clutch is automatically disengaged and the plough is locked in the raised position. Another pull on the trip-cord releases the locking device and the plough falls back into work.

There is a very marked modern tendency to mount medium-sized ploughs directly on to a suitable tractor on the " unit " principle, the plough being raised by means of the tractor's hydraulic lifting gear. The unit plough has many advantages over trailed types, being simpler, lighter and cheaper (Plate V). On some tractors the depth of working of the unit plough is controlled entirely by the hydraulic regulating gear, without the assistance of land wheels. On others, while the plough is lifted clear of the ground by the hydraulic lift gear, control of depth of working is by screws or levers and a cranked land wheel, as in a trailed plough.

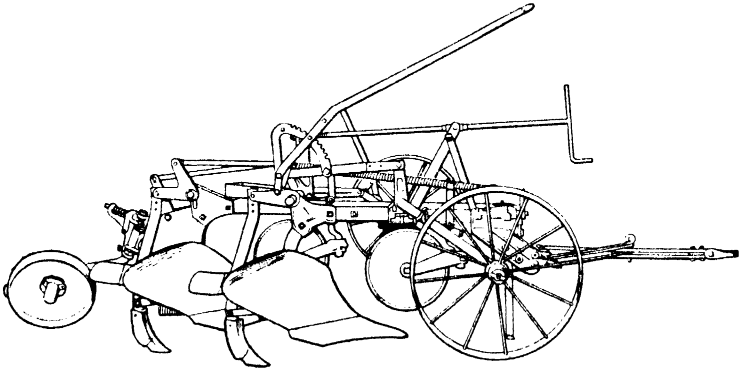
One-way ploughs working on the unit principle provide the neatest and handiest kind of one-way tractor outfit. With the ploughs raised clear of the ground the tractor can spin round in its own length, and it is easy to turn back down the last furrow, with a reasonably narrow headland.

Where very deep or difficult work is to be done, specially strong and heavy tractor ploughs are used. These heavy ploughs are frequently pulled by tracklaying machines, though there are deep-digging single-furrow ploughs which can be dealt with by wheeled tractors. Implements which will plough 18 in. deep and subsoil a further 6 in. are now widely used.

The cable system of cultivation, whereby two engines fitted with winding drums remain at the edges of the field and pull the plough or other implement to and fro, was widely used before the advent of the tractor, but is now completely out-moded. A few sets of steam cable tackle are still used, but labour requirements are so high that this form of cultivation cannot seriously compete with cultivation by the use of heavy tracklayers.

Subsoil Ploughs. On certain types of land it is desirable occasionally to stir the soil very deeply—below normal ploughing depth—in preparing for root crops. It is particularly necessary to do this where repeated ploughing at the same depth has caused the formation of a " plough pan ", or where precipitation of iron salts in the soil has formed a rock-like " iron pan ". In these circumstances there is little doubt that subsoiling once every few years leads to better crops and is well worth the extra cost.

The methods used for breaking up the subsoil vary, but the general aim is to stir the lower layers without bringing unweathered subsoil to the surface. Though horse implements exist, the operation, which requires strong equipment for its effective performance, is now almost always carried out by tractor power. A simple method, suitable for use where medium-powered tractors are employed, is to replace the front body of a two-furrow tractor plough by a subsoil tine which works in the bottom of the furrow previously ploughed. Certain types of heavy tractor ploughs can be fitted with a subsoiling tine which operates behind the plough body (Fig. 23). Such implements can plough 12 to 18 in. deep and subsoil a further 6 in. A further method is to use a special tractor subsoiler consisting of a single tine mounted on a heavy two-wheeled self-lift implement. The frame of such an implement may be used for carrying either a subsoiler or a mole drainer.



[*Ransomes*]

FIG. 23.—DEEP-DIGGING PLOUGH WITH SUBSOILING TINES.

Subsoilers for mounting directly on the 3-link hitch of medium-powered tractors are also available, and are capable of working effectively down to about 15 in. deep.

Ridging Ploughs. Ridging ploughs have a narrow share and double mould-boards, and are used to form ridges in preparing the land for planting potatoes and, in some districts, roots. The horse ridger is normally a single-row implement mounted on a beam in the same way as the common plough. Three-row ridgers for horse work are also used, but the modern tendency is to mount the ridging bodies on a tractor tool-bar. The ridger is used after the land has been worked to a deep tilth. The width between ridges is generally 24 to 30 in., but is varied to suit the soil and the crop. When the ridges have to be " split ", as in covering potatoes after planting, a flat-topped ridge is easier to work on than one which is set up to a sharp point.

THE SETTING AND OPERATION OF PLOUGHS

All types of plough are similar in essential components, and all must be correctly set for the performance of a satisfactory standard of work. With the horse plough bad setting is often easily apparent because of the difficulty the ploughman has in handling his implement. With tractor ploughs, however, important faults in setting may pass almost unnoticed except to the expert eye.

Adjusting the Share. The plough body should run level and smoothly, and correct adjustment of the share plays a large part in securing this result. The point of the share is given, in manufacture, a slight pitch in two directions—downwards and towards the landside. Faults in the fitting or setting of the share can sometimes be masked a little, but can never be completely remedied by adjustments elsewhere. On many modern ploughs the pitch of the whole plough body in relation to the beam can be adjusted. There is usually no special provision for adjusting the pitch of the share, except in the leverneck type of body ; but care must be taken to avoid upsetting the correct pitch when, for example, steel shares are sharpened.

Adjusting the Coulters. The knife coulter is set with its point sloping slightly forward, the point itself being ½ to 1 in. above the point of the share, and about ½ in. towards the unploughed land. As with all cutting tools, there must be a clearance behind the cutting edge of the coulter so that the side which is towards the unploughed land does not rub hard against the furrow wall. When the disc coulter is used to make the vertical cut, as on most tractor ploughs, it should be set for average conditions about ⅜ to ⅝ in. to the landside of the share point, and with its centre just above the share point when viewed from the side. Bad coulter setting is one of the commonest faults of tractor ploughing. Owing to the method of adjustment by a cranked stalk, discs always tend to run too narrow, and settings should be checked occasionally to see that they have not slipped. Too narrow setting of discs leads to increased draught and wear and produces work of bad quality.

Modern disc coulters for tractor ploughs have a fitting which allows them to be tilted. A good effect may often be produced in rough conditions, where a skimmer will not work, by setting the disc over two to three notches so that the lower edge undercuts the unploughed land, thereby producing a crested furrow.

On some types of wet, heavy land, where any form of coulter chokes, " wing " shares which have a vertical fin attached to the share sometimes work well.

Skim coulters are of two main types, viz. that with a straight shank which is attached directly to the plough beam, and that which is attached to the arm of the disc coulter and swings with the disc. In either case the skimmer must be set close to the disc to avoid blocking. In bad conditions the independent skimmer sometimes works best. The skimmer is generally set to cut a small " neck " of soil from the top left corner of the furrow slice, so that when the furrow is turned, weeds or turf are prevented from growing up through the cracks between adjacent furrows. Skimmers should generally be set well forward, so that the cut is made before the top of the furrow is disturbed by the share and mould-board. As a rule, only a small cut about ½ in. deep and 1 to 1½ in. wide should be made ; and the cut piece should roll into the bottom of the furrow, so that the furrow slices are not held apart by it.

Adjusting the Mould-board. It is not often necessary to interfere with the setting of the mould-board. Where the furrow slices will not turn over properly there may be a temptation to try to complete the turning by setting out the tail of the mould-board ; but this generally makes matters worse and causes increased wear and draught. The most common cause of furrows failing to turn is too narrow a furrow width in relation to the depth. As a rule, a furrow slice which is not pulverised in ploughing must have the width about one-and-a-half times the depth if it is necessary, as it generally is, to turn the furrow well over. The width of furrows on most tractor ploughs is adjustable within small limits, though the adjustment is frequently not an easy one.

Adjusting the Hitch and Wheels (Trailed Ploughs). With plough body and coulters correctly fitted and set there remains the adjustment of the hitch and wheels. It should be emphasised that with horse ploughs, and to a certain extent with tractor ploughs, the required depth and width of work are achieved primarily by adjustments of the hitch. The depth of work is increased by raising the hitch on the front of the plough, and the width of cut is increased by moving the hitch point away from the unploughed land. The wheels are used to steady the plough in the required position.

With tractor ploughs, where depth adjustments are made by the levers controlling the wheel positions, it should be realised that the hitch is also important. If the rear wheel or landside presses hard on the furrow bottom, the hitch should be raised at the hake-plates so as to pull the nose of the plough downwards. If, on the other hand, the rear of the plough runs well clear of the furrow bottom, the hitch should be lowered until the rear wheel or slade just touches the furrow bottom.

Horizontal adjustment of the hitch sometimes presents difficulty owing to the " side-draught " which is caused by the plough not being set squarely behind the tractor. Where side-draught cannot be avoided, as with a single-furrow plough, the hitch should be offset on the tractor so that the side-draught is distributed between the tractor and the plough. If the hitch is offset on the tractor so much as to create ideal conditions for the plough it will probably be impossible to steer the tractor ; while if the plough is hitched to the middle of the tractor the plough will "crab" badly. The bad effects of side-draught are minimised by a long hitch, so that the angle of pull is reduced.

Setting of Mounted Ploughs. The principles of setting tractor-mounted ploughs are similar to those already outlined, except that the pitch and sideways movement of the whole plough are controlled through the linkage which connects the plough to the tractor. The pitch of a mounted plough is readily varied by altering the length of the top link. Sideways movement of the mounted plough is a little more difficult to understand. The usual method on ploughs connected to the tractor by a 3-point linkage is to employ a mechanism which in effect makes one of the lower connecting links longer than the other. This has a tendency to make the plough run at an angle to the direction of travel; but the soil forces immediately tend to make the plough run straight ahead again, and the net result is that as the outfit moves forward after the adjustment has been made, the implement swings to one side and then runs more or less straight ahead in its new position. A common method of achieving this result is to mount the plough's hitch pins on the ends of a cranked cross-shaft which can be rotated by means of a screw mechanism.

Mounted ploughs without a depth regulating wheel depend on the tractor's automatic draught control mechanism to ensure that the plough runs at the chosen depth. In normal soil conditions in Britain such mechanisms can give entirely satisfactory results, and this method has the merits of lightness and simplicity of the implements, coupled with very easy alteration of working depth through the medium of the hydraulic control lever.

Some plough-setting faults caused by incorrect hitching, and the remedies, may be summarised as follows:

Fault.	Remedy.	
	Trailed ploughs.	*Mounted ploughs.*
Plough will not penetrate.	Raise hitch at hake.	Shorten top link. Set top link and draught links in lower position on tractor.
Plough will not run shallow.	Lower hitch at hake. Fit extension rim to plough if necessary.	Lengthen top link. Set top link and draught links in upper position on tractor.
Uneven depth of ploughing.	Re-set hitch at hake.	Re-set top link.
Front furrow too wide or too narrow.	Re-set hitch on tractor.	Check setting of tractor wheels Adjust cross shaft on plough.

METHODS OF PLOUGHING

Most ploughs in use today turn the furrow slices to the right, and with such ploughs it is impossible to plough a field by starting along one side and working to and fro until the other side is reached. The method commonly adopted in ploughing with horses is briefly as follows: The headland is first marked off by turning a shallow furrow 5 to 6 yd. from the boundary of the field. Ridges are then drawn parallel to one another across the field, the distance apart being normally about 22 yd., but being varied according to local requirements. The distance between the headland furrow and the first ridge is made one-quarter of the normal distance beween ridges.

There are various methods of setting up a ridge, the commonest being to turn a shallow furrow and then, turning right at the end, to turn another furrow towards it so that the two just meet, leaving an unploughed strip beneath. If this job is really well done and the land is clean this method is satisfactory for many crops, but a more thorough method is to split the ridges before setting up the " top ". To do this, a left turn is made after drawing the first shallow furrow, and the second furrow is thrown away from the first. On the third trip across the field the second furrow and the undisturbed soil beneath it are turned together towards the first furrow ; and on the fourth trip the ridge is completed by turning the first furrow and the soil beneath it so that it just touches the other pair of furrows.

Ploughing then proceeds by working clockwise round and round the first ridge until a strip 11 yd. wide has been ploughed. The same process (called " gathering ") is repeated round the second ridge, and then the 11-yd. stretch left between the strips is worked out by turning anti-clockwise, this process being termed " splitting " or " casting ".

When the last furrow between the lands is finished, a wide open furrow is left. It is usual to leave the field thus, but sometimes a deeper drainage or " mould " furrow is drawn in the bottom, while in other conditions the land may be levelled a little by ploughing back the last two furrow slices. When all the lands are finished the headlands are finally ploughed by working round and round the field.

With tractor ploughing similar methods may be followed, but headlands are generally made wider. The ridges are set farther apart except where drainage considerations rule otherwise, and short turns are avoided by working two ridges at once.

Ploughing round and round the field is quite common in some areas, especially where there are large fields, as on the Downs. There are various methods of dealing with the turns, the commonest being to have the corners rounded and to keep the plough at work all the way. A more thorough method is to mark out headlands along the diagonals, lift the plough at the turns, and plough these internal headlands last. Where a field has some gradual turns and some sharp corners it may be advisable to make a headland and lift the plough at the sharp corner, but to plough round the gentle curves.

A popular method for deep work is called " square ploughing ". The field must be fairly regular in shape, and a land is ploughed out in the middle of such a shape that the boundaries of the field are equidistant from the adjacent sides of the ploughed part. The field is then ploughed by working clockwise round this central part, the plough being raised at every corner and a clockwise loop made to bring the outfit round ready for dropping the plough into work along the next side. With careful attention to raising and lowering the plough, extremely good work can be done, all the land being ploughed and troublesome open furrows eliminated.

Essentials of Good Ploughing. It is now generally agreed that some of the fine points of style that used to decide ploughing matches are of little practical significance. The more important factors today may be listed as follows :—

1. All the land should be ploughed, including that under the "top" or ridge, so that subsequent cultivations may be carried out without trouble.
2. All rubbish and manure must be completely buried.
3. The plough furrows should be left in the condition desired. This may be rough, for easy weathering ; or well pulverised for rapid preparation of a seed or plant bed.
4. The depth of work should be uniform.
5. Unless drainage conditions require something different, the land should be left as level as possible, the ridges not being too high and the open furrows not too deep. Attention to this point greatly facilitates seed-bed preparation.

CULTIVATORS

Cultivators are implements which are commonly used for breaking clods and working soil to a tilth in the production of seed-beds. Other uses include the killing of weeds and mixing of fertilisers with the soil. Cultivators and harrows are tined implements, cultivators usually having wheels and being heavier than harrows, and used for deeper work. The terms cultivators and harrows are, however, loosely used, and some implements which are called harrows are equal in effect to cultivators.

Various types of tine may be fitted, according to the kind of work to be done. On horse machines spring-mounted curved tines of sickle shape are most commonly used, the tines being mounted in two rows with front and rear tines "staggered" to allow clods to pass through easily. The springs allow the tines to yield a little when they strike large clods or very tough land, and it is claimed that the vibrating motion assists in pulverising the soil and reducing the draught. It is doubtful, however, whether this effect is of much consequence in most conditions, and the modern tendency on tractor cultivators is towards strong, rigid tines. Penetration is achieved mainly by virtue of the pitch of the shares, rather than by the weight of the implement. Various types of share can be fitted to the tines, some being narrow and designed for deep working, while others are broad and designed for such jobs as cutting all weeds just below ground level.

When tractors are used for cultivating there is usually every advantage in using the mounted type, rather than a trailed implement. The mounted implement is simple, cheap and sturdy, and it is only where heavy tracklayers are used that trailed implements are normally preferred.

New types of cultivator/harrows designed for work at high forward speed employ a large number of spring tines (Plate V).

The heaviest tractor cultivators may be used for bursting up unploughed land in the same way as the heavy cultivators operated by steam cable tackle used to do. This is sometimes the best way of starting a fallow, though it is generally better to plough first where this is possible. The heaviest cultivators normally require very powerful tracklayers to pull them.

The *Broadshare* is a heavy type of cultivator fitted with shares up to 18 in. wide. This implement can work very hard ground to a depth of 2 to 3 in., and is useful for stubble cleaning. In some districts frequent use is made of a " thistle-bar "—a steel blade 6 ft. long, 3 in. wide and about ½ in. thick, which is sharpened at its forward edge and bolted to the tines of a heavy cultivator. It is used on heavy land in preparing seed-beds for roots, when it is undesirable to disturb the surface tilth by deep working.

HARROWS

Harrows are generally used for shallow cultivations, in operations such as the preparation of seed-beds, covering seeds, destroying seedling weeds, and so on. The commonest form of harrow is called the *Zig-Zag* harrow. It has the tines staggered so that the rear ones do not follow the same tracks as the front. The lightest type has short, straight tines ; and three sections totalling about 8 ft. wide may be pulled by a single horse in most conditions. It is called a *Seeds* harrow, because it is used for the final touches in preparation of seed-beds and for covering seeds after the drill, as well as for very light weed-control operations. When used for covering seeds, the harrows are now often hitched directly behind the drill.

The heaviest kind of zig-zag harrows, called the *Duck-foot* or *Drag* harrow, has curved tines and often wheels, and is capable of quite deep work. The action of the drag harrow is, in fact, very similar to that of the cultivator, the main difference being that it has more tines and does not, as a rule, work quite so deep. On difficult land it is often found that the drag harrow produces a better effect than the cultivator in the preparation of spring seed-beds, as it does not bring so many unweathered clods to the surface.

The *Spring-tined* harrow consists of a number of sickle-shaped spring tines mounted on frames 3 to 4 ft. wide. It can be adjusted to produce very variable results, the tines being set at various angles and depths by means of a lever. Its great advantage is that it can be set to do all kinds of work from that of a very light harrow, when the points of the tines are vertical and only scratching the surface, to that of a light cultivator, when work up to 6 in. deep can be done. It is popular on small farms in many parts of Europe, and its use in Britain seems to be extending.

Chain harrows have no rigid frame, being built up of a series of flexible links. As the name suggests, the original chain harrows consisted simply of a number of chain links joined together to form a rectangle. The main use of this type of harrow was rolling up weeds which had been pulled free from the soil by other implements. Spiked link harrows were soon found more generally useful, and most of the flexible harrows in use today have teeth of one sort or another. One common type has the teeth formed by an extension of the link. Another type, primarily for tractor work, has knives carried in cast-iron sockets which are flexibly linked together. Some spiked flexible harrows have on one side long tines, suitable for use on arable land, and shorter ones, suitable for use on grassland, on the other.

On uneven land flexible harrows follow the surface irregularities better than rigid types. On such work as harrowing pastures, semi-rigid harrows, such as the zig-zag, jump about too much to be of any use, while spiked flexible harrows work steadily if the surface is not too hard.

With the lighter harrows a full load for the tractor often necessitates a very wide implement—e.g. 20 to 30 ft. wide for the lightest types. It is often not economic or convenient, however, to buy such a wide harrow ; and it is frequently found better to do two operations, e.g. harrowing and rolling, with the implements arranged in tandem. When it is necessary to work tractor harrows in rubbish, it is very desirable for the harrow to be self-cleaning. It should also be easily transported from field to field. Many special tractor harrows have been developed for direct mounting on the power-lift linkage and these are becoming widely used. Among special self-cleaning types is Wilder's " Pitch-Pole " harrow, which has two sets of teeth mounted at 180° to one another, so that when one set of teeth is at work the other set is in the air. The teeth are mounted on axles which can rotate in the rectangular frame. A pull by the tractor driver on a trip-cord causes the tines to revolve through a semicircle, the rubbish being dropped as they do so. Depth of work is regulated by levers working on wheels at the sides of the harrow, and there is a choice of tines for arable and pasture work.

Tractors having a power lift which operates a rocker shaft at the rear can fairly easily be fitted with a device which will raise harrows clear of the gound ; and this method is successfully used for lifting a zig-zag harrow when potato tops are being collected together.

Disc Harrows have a series of saucer-shaped discs mounted on two or more axles, which may be set at an angle to the line of draught. The discs are generally from 12 to 20 in. in diameter, the larger sizes being capable of deeper work. The action of the discs depends largely on the angle at which they are set. If the gangs are set perpendicular to the line of draught, penetration is at a minimum. Penetration increases with the amount the discs are " angled ", until the position is reached at which the forward edges of the discs lie tangential to the direction of travel (Plate VI).

Disc harrows are particularly valuable for the preparation of seed-beds after old turf or leys, where the use of tined implements would bring turf to the surface. They are also now widely used for preparation of spring seed-beds on all kinds of arable land—especially where it is undesirable to cultivate very deeply. An advantage of disc harrows is that when the soil is in suitable condition to be reduced to a tilth, the discs will do the work more rapidly than the common tined implements ; the fewer operations necessary result in a smaller loss of moisture—an important consideration in preparing spring seed-beds.

The draught of disc harrows is heavy, but a medium-sized general-purpose wheeled tractor can generally pull a medium-weight tandem disc harrow 6 to 8 ft. wide. The tandem disc harrow is, in fact, one of the few types of harrow that will provide such a tractor with an adequate load. Light tractor mounted discs are now widely used.

Like all tillage implements, disc harrows have some limitations and disadvantages, chief among these being the rather high first cost, a greater rate of depreciation than comparable tined implements, and some difficulty in transporting the implement along roads. It should be remembered that discs may do harm if used in the wrong conditions, as on heavy land that is too wet or on land where there is couch (twitch). It is possible, however, to misuse any implement, and there is no justification for decrying the use of disc harrows on this account.

ROLLS

Rolls are used to consolidate the soil, to crush clods, to smooth the surface of the soil, to prepare a surface for the drilling or broadcasting of seeds, and occasionally to break a surface crust. Consolidation is necessary in some soil conditions to give plants a firm root-hold and to ensure continuity between subsoil and top-soil. This is particularly necessary in spring, after winter frosts have raised the soil surface. The crushing effects of rolls need no explanation, apart from emphasising the importance of choosing the right time to do the work. The effects of rolls, with regard to both consolidation and clod crushing, are largely bound up with the soil moisture content. Rolls cannot be used when the soil is wet ; and when it is dry the effects are often negligible. There is, however, an intermediate stage, when the clods have been wet and have started to dry, at which the optimum results from rolling can be achieved.

Rolls must, of course, be used with caution on clay soils. It is seldom advisable to roll such soils in autumn owing to the danger of getting too fine a tilth, so that the surface runs together in winter. In spring, rolling must be delayed until the soil is reasonably dry underneath as well as on top, especially in conditions where the soil is short of humus.

Spring rolling of autumn sown corn is a common practice, and experiments show that the small expense is well justified, quite apart from the important matter of levelling the ground for the binder at harvest. Such rolling sometimes produces markedly good effects in conditions where the soil is loose and wireworms or other soil pests are active.

Many types and sizes of rolls are used on farms, but two types predominate, viz. the *Flat* roll, which has a smooth surface, and the *Cambridge* or *Ring* roll which has a ribbed surface. The flat roll usually has two or three sections mounted loose on an axle in an implement about 7 ft. wide, so that the soil is not so much disturbed when the roller is turned as it would be if the cylinder were continuous.

Diameters cover a wide range, with a majority about 18 to 30 in.; and the average weight is about 10 cwt.

The Cambridge roll consists of a number of rings, generally 3 in. wide, and having a rib about 1½ in. high. The rings are mounted loose on an axle, so that turning is easy, and intermotion of the rings keeps the surface clean. This roll is generally heavier than the flat type, and is more effective as a clod crusher. It leaves a characteristic soil pattern in which narrow, well-compacted grooves about 1½ in. deep and ½ in. wide are separated by small, rounded ridges which are only lightly compressed. This surface is a very suitable one for many conditions. It can be left after drilling without fear that it will run together as badly as a flat-rolled surface often does; and it is often convenient to broadcast small seeds, such as grasses and clovers, on the corrugated surface, covering them by a subsequent harrowing or flat-rolling.

When tractor power is used for rolling the Cambridge type of roll is almost invariably used. While single swing-type implements are often used, the width of work is limited, and triple rolls are commonly used where a wide strip must be covered. Three rolls, each about 8 ft. wide, are provided with a hitch which permits them to be run in tandem for transport, and so that they just overlap when at work.

The Furrow Press is a very heavy type of roll with wedge-shaped press wheels which are designed to break down the lower parts of the furrow slices after ploughing. The press is now generally of a multi-ring type and is trailed behind the tractor plough. It is regularly used in some districts when ploughing out leys in preparation for wheat.

The Planker or Scrubber is a simple implement which is sometimes used for breaking down clods on land where it is impossible to use a roll. It is constructed of planks approximately 6 ft. by 10 in. by 2 in., fixed together so that they overlap about 2 to 4 in., the corner thus formed being shod by an iron bar. When the implement is pulled over the ground it scrapes the surface and rolls the clods over, creating a tilth and smoothing the top. It can occasionally be used when the soil is still wet below and use of a roll would be inadvisable.

The Float is an implement which is used in the preparation of very smooth seed-beds for root crops. It consists essentially of a framework carrying two or three boards or metal plates, which can be set at a slight angle so that they work on the soil rather like a plane. The float picks up soil from the high places and drops it in the hollows.

Some farmers drag a single plank just in front of the drill coulters, in order to obliterate the marks made by the horses' hoofs or tractor wheels.

ROTARY CULTIVATORS

Rotary cultivators of various types were invented and used at an early stage in the application of steam power to agriculture. None of the early steam-powered rotary cultivators, however, achieved any substantial success. The internal combustion engine is a more satisfactory power unit than steam for almost all field work, and in recent years several satisfactory types of rotary cultivator have been produced.

Machines now available include very small two-wheeled hoeing units with a cut of about 10 in., sturdy two-wheeled units with engines of 5–8 H.P. designed to do all the basic cultivations on market gardens, and wide tractor-mounted or trailed outfits designed for operation from the power take-off of ordinary farm tractors. The engine drives a horizontal rotor situated at the rear of the machine, and the outfit is equipped either with spring-mounted or spring-steel chisel-shaped tines, or more usually with sturdy hoes which successively enter the ground as the machine travels forwards. The rotor is covered by a hood, and working depth ranges from 3–4 in. with the smallest machines to 8–9 in. with larger models (Plate VI).

The rotary hoe has been found effective for the preparation of seedbeds and for such work as stubble cultivation on many farms ; and now that units which can readily be fitted to ordinary farm tractors have been developed, a steady increase in the use of the power-driven cultivating tools on farms as well as on market gardens, may be expected.

INTER-ROW HOES

When root crops became extensively grown during the nineteenth century horse hoes were widely used to assist in keeping the land clean. The primary object of hoeing is to kill weeds, and experiments show that hoeings additional to the amount required for weed control are seldom justified. Competition from weeds checks the growth of the crop right from the first week or so after germination, and it is necessary to start hoeing root crops at a very early stage. The surface mulch created by hoeing appears to be of some value in improving soil moisture conditions (by providing an insulating layer between the moist soil below and the atmosphere) ; but it has been shown that the effects on moisture conservation are not, as a rule, so great as used to be supposed.

It is important to be able, at an early stage in the growth of root crops, to hoe close to the crop plants without smothering them. The best type of hoe blade for such work has a vertical knife which is continuous with the L-blade. In some conditions, plain or concave discs running close to the plants opposite the L-blades permit very close work ; but the extra cost and complication of such equipment is a disadvantage.

TRACTOR TOOL BARS FOR INTER-CULTIVATIONS

The main features of row-crop tractors have already been described. The cultivating tools may be attached at the rear, between the wheels, or in front of the all-purpose tractor, and they are generally mounted on tool-bars in such a way that they can be raised or lowered by means of the hydraulic lift. For inter-cultivation of potatoes after the crop has been planted, rear-attached tools are generally most satisfactory. With root crops, on the other hand, when it is necessary to hoe close to the rows, the best position of the hoes for a one-man outfit is on a tool-bar lying ahead of the rear wheels. Individual hoes or groups of hoes working each row should float independently in order to work efficiently on uneven ground. Good work can be done by rear-attached hoes which are independently steered ; but this method is wasteful of manpower. Some light tractors which are primarily designed for hoeing have the power unit and transmission mounted over the rear axle, and have the hoes mounted on a frame in front of the driver in such a way that they can be seen clearly and adjusted with ease (Plate VII).

The best tractor hoeing outfits are at least as good as horse hoes, and a steady extension of the use of tractors for hoeing may be expected. Where horses are available they are often used for hoeing because, apart from any other consideration, the tractor is required for heavier work elsewhere. Some farmers use a tractor for hoeing because, where the acreage of roots warrants the time spent on fitting the tool-bar, the time saved in operation may be considerable. It is quite practicable on flat fields to hoe 8 rows of sugar beet at a time, where the same tool-bar has been used for drilling ; and the use of 4-row potato planters, scufflers and ridgers in place of the customary 3-row has advantages in addition to the extra speed of work. With 4-row equipment, potatoes do not have to be planted in tractor wheelings ; and later on, none of the rows has tractor wheelings on both sides.

COMBINED TILLAGE OPERATIONS FOR CLEANING LAND

The Bare Fallow. Bare fallow is the term given to land which is left uncropped throughout a whole year, during which time it is cultivated with the object of killing weeds. The system was formerly more generally adopted in England than it is at present and it formed an essential part of the three-field rotation under the Manorial system. It is also part of the normal system in some dry-farming areas of the world, notably in some parts of North America and Australia, where the collection and storage of rainfall in the soil during the fallow year is one of the main functions. In Britain today the bare fallow has been largely discarded in favour of shorter spells of cleaning. Improvements in tillage implements and increased use of tractor power have made it possible to keep the land clean without resort to an expensive and entirely unproductive year. There are, however, still a few farmers on heavy land who employ the system, and a brief outline of the methods employed in fallowing such land is given below.

The operation normally follows a corn crop, and the first point to note is that the land must be left undisturbed all through the winter and early spring. The object is to kill the weeds (e.g. couch) " in the clod " by desiccating them, and the first operation is to plough after all risk of severe frost has passed. The first ploughing should be done to full depth, using a lea type plough, preferably when the soil is wet. When dry weather follows, the furrows dry out hard and do not crumble. When the buried vegetation has been well smothered and the furrows are fairly dry they are ploughed back again in order to separate them completely from the subsoil and to dry out the other side. The object at this stage is to keep the soil in large clods and avoid the formation of tilth.

The next operation depends on the equipment available. The field may either be cross ploughed, or cross-cultivated with an implement having very few tines, the object being to break the furrows into very large clods. After this the clods should be stirred and turned over when the weather is hot and dry. If the field is kept on the move during a dry spell of 10 days or so the fallow will have been " made " and the rest of the job is easy. Adequate tractor power enables the land to be kept on the move in dry weather in a way that was almost impossible with horses.

Towards harvest time or earlier the fallows begin to crumble to a tilth, and then the weed seeds begin to germinate. These may be killed by a final ploughing, and this also serves to cut thistles, which are sometimes still quite strong after a fallow.

The efficient farmer today generally plans his cropping and arranges his tillages so as to avoid any necessity for a bare fallow. If the land becomes very foul it means that either the farming system is at fault or that the tillage operations are not fully effective. If, however, the land should by some mischance become so foul as to need a thorough cleaning it becomes advisable to make a bare fallow to remedy the situation. It should be mentioned, in passing, that a bare fallow has good manurial effects on the soil, as explained on page 165.

The Bastard Fallow. The bastard or half-fallow is a cleaning operation which is carried out after a crop has been removed from the land in early summer. For example, it may be carried out after mowing the first cut on a dirty piece of " seeds ", or after an arable silage crop has been removed in June or early July. In general, this is a cleaning method which can be recommended, especially for heavy land. The shorter period of the fallow naturally provides fewer opportunities of prolonged spells of dry weather ; but if advantage is taken of good weather that does occur it is seldom impossible to achieve satisfactory results. The method is to plough and kill the weeds in the clod, as in a bare fallow.

The main difficulty about a bastard fallow is that the land may be too hard to plough properly after the crop is removed. There are occasions when only a heavy tractor and a very heavy cultivator will make much impression on the hard-baked land. There are also years when July and August are persistently wet, and in this event the bastard fallow is not likely to succeed. There is also little opportunity for germinating and killing annual weed seeds.

The advantages of a bastard fallow compared with a bare fallow are that a crop is obtained, and that if this crop is a satisfactory one the weeds are well drawn up and smothered before cultivations begin, while the total cost of cultivations is less.

Autumn Cleaning. With both bare and bastard fallows cleaning the land depends mainly on drying out the perennial weeds " in the clod ", and no weeds are pulled out and burnt. In autumn or stubble-cleaning, however, though killing in the clod may be employed in especially favourable dry spells, the normal practice is to employ quite different tactics. The weather is often unsettled after harvest, and the object in autumn cleaning is generally to break the soil down into a fine tilth so that the weeds may be shaken free from soil, pulled out, and burnt. In addition, an effort is made to make weed seeds germinate, so that they may later be killed.

The first operation after harvest has been cleared—or even between the rows of stooks—is to separate from the soil below a layer of soil 3 to 4 in. deep, in which most of the weeds are growing. The usual method of doing this is by ploughing, but broadshares, heavy cultivators and sometimes disc harrows are also used. Speed of working is essential, as the time available before the land becomes too wet is restricted. The land is then harrowed or worked with any convenient tined implement until a tilth is obtained and the weeds come free from the soil. They may then be collected by chain harrows, gathered into heaps and burnt. In carrying out these operations a fine tilth will have been created, and after a week or two a crop of weed seedlings may appear. Further cultivations will destroy these seedlings and help to germinate a second crop.

The success of stubble-cleaning depends mainly on starting early while the land is still dry, and before the weeds have time to recover from being drawn up and shaded by the crop. The method is particularly useful when early-sown roots or spring corn are to follow, for in such cases there is seldom time to do any effective cleaning in spring without unduly delaying the sowing date. If full advantage is taken of opportunities of autumn cleaning, the standard of cleanliness of the farm is improved and better crops are secured.

Spring Cleaning. Spring cleaning is a technique which is normally employed just before sowing late-planted roots. It commences with a winter ploughing which is deep enough to be below the couch or similar rubbish, and the land is then left until it begins to dry out in spring, and the rubbish begins to grow through. At this stage the field is ploughed again, in order to dry the land and bring the weeds back to the surface. Cultivators and harrows are then used, especially in dry weather ; and if the couch is dense it may be pulled out, collected and burnt as in autumn cleaning. Often, however, if the land is not excessively foul and a dry spell of weather ensues, the weeds may be so thoroughly dried out that it is safe to plough them under or, if there are not enough to cause hoes, etc., to block, they may be left on the surface. Spring cleaning may sometimes be quite successful if a prolonged dry spell is followed by nice rains when the crop is seeded ; but in some seasons the rain comes in the period when cleaning is being attempted, or the land remains dry so long after sowing that germination and subsequent development of the crop are impaired. For these reasons spring cleaning is not a practice that should be regularly followed. Where autumn cleaning is possible it is generally to be preferred.

The Influence of Mechanisation on Tillage Practices. In general, the mechanisation of tillage operations has taken place without many fundamental departures from traditional methods. The only outstanding exception to this generalisation is the rotary cultivator, which has become well established. Reciprocating harrows show promise, but most tractors pull ploughs, cultivators, harrows, etc., which are fundamentally little different from horse implements.

Mechanisation makes it possible to telescope tillage operations, as by ploughing, pressing the furrows, drilling and harrowing in one trip across the field. It is, however, only in rare conditions that such complex operations can be advocated, though more limited combined operations such as harrowing and rolling together may often be undertaken with advantage.

Adequate tractor power and suitable implements make it easy to undertake operations which would be difficult to accomplish without them. For example, cleaning operations which would require a bare or bastard fallow with horses may often be accomplished in a quite short spell of dry weather if the tractors are kept constantly at work.

Suitable implements and tractor power have made it possible to cultivate the land deeper than hitherto, and in many instances the deep ploughing and subsoiling have unquestionably resulted in improved crop yields.

Chapter VI

FARM MACHINERY

BROADCASTING MACHINES AND SEED DRILLS

SEED is now most commonly sown by means of a drill, which places the seeds in the soil in rows and covers them. Broadcasting by hand is, however, still practised for certain crops and field conditions, while broadcasting machines are used in preference to drills for the sowing of particular crops. The advantage of broadcasting for such a crop as a grass and clover ley is that a more complete covering of the ground can be achieved than is possible with a drill. The disadvantage is that the depth of covering is irregular and that much of the seed may be left on or very near the surface, even after harrowing to cover it. In conditions of soil and climate where the upper layer of the soil dries out badly it is essential to place small seeds well into the soil, and this can only be economically and efficiently done by use of a drill.

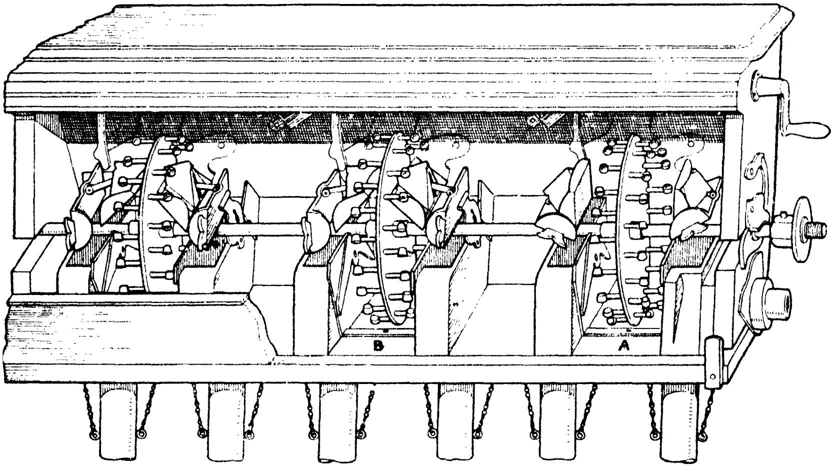
Broadcasting Machines normally consist essentially of a long hopper, with rotating feed units placed at intervals along it. The simplest type is the seed barrow, in which the seed box is mounted transversely on a light barrow frame and the feed mechanism consists of a revolving brush which is driven from the wheel, and which sweeps the seed through adjustable holes in the rear of the hopper. Similar machines, some with fluted roller feed, are mounted on two wheels and fitted for horse or tractor work. Where broadcasting machines are used on bare ground some form of marker or system of sighting rods is required to avoid gaps or overlapping.

The *Fiddle* is a small broadcasting device which is popular in some districts, especially for sowing grass and clover seeds on hilly land. It consists of a hopper and a light mechanical distributor, which are strapped to a man's shoulders. As the operator walks along, the seed pours in a thin stream on to a horizontal ribbed disc, which is rotated by a rack and pinion mechanism, the rack (or bow) being pushed to and fro as the operator walks. The seed is thrown out a considerable distance by the rotating disc. The chief disadvantages of the fiddle are that some experience is required to secure an even cover, especially if the weather is not perfectly calm ; and the heavier seeds tend to be concentrated at the edges of the bout.

Seed Drills. Most of the drills used in Britain are of a general-purpose type, being capable of sowing almost any kind of seed. There are, in addition, various special types of drill for such jobs as sowing roots on the ridge.

The general-purpose drill consists of a seed box, carried on a pair of land wheels, and having a feed mechanism driven by gearing from the wheels. The seed passes down seed tubes to the coulters, which cut grooves in the soil. The seed rate is adjusted by variations of the feed mechanism and the gearing. The depth of sowing and the width between rows are controlled by the setting of the coulters. A simple device is provided for raising the coulters clear of the ground and putting the feed mechanism out of gear. The farmer has to choose between drills having various types of feed mechanisms and coulters. The agricultural merits of the most common types are, therefore, given below.

A type of feed mechanism still widely used on British drills is the *cup-feed*—which has been in general use for a very long time. The seed hopper is divided into two parts, a top box containing the bulk of the seed and a lower one divided into small hoppers in which the delivery mechanism rotates. The seed flows through shutters from the top hopper to the feed boxes. The shutters must be adjusted to ensure that the feed box contains sufficient seeds to fill the feed cups, but not an excess. The seed " barrel " which rotates and picks up the seed consists of a long spindle carrying a series of discs, with a ring of cups attached to the periphery of each disc. Each cup picks up a few seeds from the feed box and drops them into the small hopper which leads to the top of the seed tube. The seed tube delivers the seed to the coulter (Fig. 24).



[*Smyth*]

FIG. 24.—MECHANISM OF A CUP-FEED DRILL.

At A the hopper chutes are shown turned back ready for the cup barrel to be removed. At B the hoppers are shown in the drilling position.

There are usually four sizes of cups, the largest being for beans, peas and oats ; the next for wheat and barley ; the third for roots ; and the smallest for tiny seeds such as clover, kale, etc. Two sizes of cup are often provided on one seed barrel, the change being made be reversing the barrel end for end. On some foreign drills the size of cup may be varied by turning a wheel at the end of the box.

The advantage of the cup feed is its ability to sow successfully all types of seeds. The chief drawbacks are that sowing may be irregular on rough land, when the seeds are jolted from the cups before reaching the hoppers; some difficulty in maintaining a constant rate of seeding on hilly land; failure to empty the feed boxes completely; and a higher cost than with some simpler forms of feed mechanism.

The other common type of feed used is called the "force feed", and is of two kinds.

The *external force feed*, consisting of a number of fluted rollers rotating in the bottom of a V-shaped hopper, is one of the simplest kinds of feed mechanism. Regulation of seed rate is partly controlled by varying the length of fluted roller in contact with the grain. The best drills of this type will sow a wide range of seeds satisfactorily. The force-feed mechanism is steady over clods and sows uniformly on hilly land.

The *internal force feed*, which is commonly used on combined grain and fertiliser drills of American design, has the corrugations on the insides of flanges which form the rim of small disc wheels (Fig. 25). This type is very efficient for sowing cereals but is not adaptable to a wide range of crops. Various other types of feed mechanism are used, but the ideal mechanism, which will space all types of seed at equal intervals along the row, is still sought.

Several kinds of coulters or furrow-openers are used on drills, the commonest being the Suffolk and single-disc types. The *Suffolk* coulter has a V-shaped shoe which cuts a groove in the soil, and the seed is delivered into the groove just before the soil falls back. This coulter works satisfactorily in most conditions, but is apt to block in rubbish and on sticky land, and fails to penetrate in hard land. The *single-disc* coulter consists of a saucer-shaped hardened steel disc which cuts a groove in the soil, and has a seed boot attached to the convex side of the disc, just below and behind the centre. This coulter works well in all kinds of unfavourable conditions, but it does not do quite such a good job as the Suffolk in good conditions, since it does not place all the seeds at the same level.

Drilling is now usually done by tractor, and in order to facilitate operation by the tractor driver alone, a self-lift or power-operated lift is provided in place of a hand lever at the rear. Trailed tractor drills are at present the type most commonly used, but types that are also in general use include semi-mounted machines which have the coulters raised by the tractor's hydraulic lift, and mounted drills which are wheel-driven but are completely lifted from the ground at the ends. The mounted type is advantageous for light work such as root drilling.

The Operation of Drills. Whether the coulters are power-lifted, operated by a self-lift or hand-operated, the action of lowering them into the soil automatically puts the drill in gear. Control of seed rate is achieved by adjusting the feed mechanism and also the drill gearing. While the chart supplied with the drill provides a good guide, it is necessary to check the quantity being sown at an early stage of the work owing to variations in seed samples. When the land is at all sticky it is advisable to drill the headlands first. There is always a lag between the operation of the feed mechanism and arrival of the seed at the coulters, and this must be allowed for whenever work is re-started after a halt. The coulters must always be raised if the drill is backed.

Care is necessary to ensure that adjacent drill bouts are parallel, and that the distance between bouts is equal to the distance between the drill rows. Some drills are equipped with a steerage fore-carriage, which is held to the line of the outside wheel-mark by an extra man. Use of tractor power for drilling steadily increases, and as there is usually ample power to pull a harrow behind the drill, a foot-board with a harrow hitch at the rear is now commonly fitted. The hitch should be designed to offset the harrows, so that the outside wheel-mark is not covered, and to allow the harrows to swing over to the other side as the drill turns. With wide drills, fitting of a marker is necessary to secure accurate work.

Special Types of Drill. While general-purpose drills can be used quite satisfactorily for drilling roots on the flat, special types of root drills are used for work on the ridge. Ridge drills are generally two-row machines, with a large concave roller preceding each coulter and a small pressing roller following. This drill is used on land which has already been ridged before drilling. Another type of root drill has pairs of sweeps which form small ridges as the work proceeds, the drill in this case working on a level seed-bed. Many kinds of spacing drill have been developed with the object of sowing the seeds of root crops in bunches at regular intervals along the row, but none has come into general use in Britain. In the United States, a special technique of spaced drilling called " check-row planting " is used for maize, in order to plant it on the square, so that it can be cultivated in two directions at right angles.

A comparatively recent development in Britain has been the fitting of root drills on tractor tool-bars. It may be expected that the use of tractor-mounted drills, like that of many other tractor-mounted tools, will extend in the future. A further important development has been the introduction of the technique of " shearing " and " rubbing " of sugar beet seed in order to increase the proportion of single plants. Drills that will sow rubbed seed singly have been developed, and some progress made with mechanical thinning of the crop by the use of " down-the-row " thinning machines.

PLANTING AND TRANSPLANTING MACHINES

The use of potato-planting machines in Britain greatly increased from 1940 onwards, and a wide variety of machines for this work is now available. The main types of planters in use today include the following :

1. Dibbling machines which facilitate hand planting by forming depressions in the soil at regular intervals along the rows, either by means of press wheels fitted with blunt spikes, or by star-shaped wheels fitted with spading devices. These ensure regular spacing and enable the potatoes to be dropped rather than placed in position.
2. Sledge type planters, provided with a hopper, a furrow opener, a covering device and a seat for the operator, who drops

the seed into the groove made in the soil as the implement is slowly pulled along.

3. Two-row, hand-fed planters mounted on power-lifted tractor tool bars. The planter unit consists of a hopper, a pair of furrow-opening coulters, and a pair of chutes down which seed is dropped by two operators. Normal ridging bodies, or special discs, follow to cover. A fertiliser placement attachment may also be used.
4. Planters with conveyor belts or turn-tables, in which the potatoes are placed in pockets on the conveyor by the operator and are then automatically deposited in the ground and covered. This type is sometimes equipped with a fertiliser placement device. Many different makes of planter of this general " semi-automatic " type are now in common use (Plate IX).
5. Fully automatic machines, in which the potatoes are picked out of the hopper by the feed mechanism, and the whole planting process is carried out without assistance from the operator. Such machines naturally require attention to ensure that everything is working satisfactorily. The fertiliser may be sown in bands alongside.

The best method of fertiliser distribution for potatoes is still the subject of experimental work. It depends on a variety of soil and climatic factors, as well as on the types of equipment used. In general, however, the practices of distributing the dressing over previously drawn ridges and of " side-band " placement are most likely to give good results.

Two main types of transplanting machines are now employed by vegetable growers for transplanting Brassica seedlings. In the simpler type the operator sits very near the ground and places the plants directly into a furrow which is opened by the planter. A pair of inclined press wheels follows and firms the soil around the plant roots. In the other type the operators place the plants in fingers on an endless conveyor belt. The belt takes the plants down to a furrow which is opened by the machine, and releases them as the press wheels firm the soil alongside. Both types require nimble-fingered operators for successful working. The work done with planting machines which have been correctly adjusted is often of better quality than that done by hand (Plate IX).

MANURE DISTRIBUTORS

Fertilisers are, as a rule, applied to the soil by means of manure distributors which are designed to operate as broadcasting machines. Uniformity of distribution is important where very small amounts of concentrated fertiliser are to be applied, and distributors must be capable of sowing evenly various sorts of fertiliser in amounts varying from 1 cwt. to about 1 ton per acre. In some circumstances, as when fertiliser is being sown along the ridges for potatoes, it may be advantageous to concentrate the manure in bands, so that none is applied to the tops of the ridges. Special devices to facilitate such a distribution may be obtained for fitting to some distributors.

A common type of distributor employs a long low hopper carried on two wheels, with a feed mechanism, which is driven by the wheels, operating in the bottom of the hopper. There are many different types of feed mechanism, the most noteworthy being the following:

Roller feed. A delivery roller rotating in the bottom of the hopper carries the manure through an adjustable opening. The roller may be plain or corrugated, and may be driven at variable speeds by means of the gearing. An agitator is generally required in the hopper to prevent the manure " bridging " over the roller, and a cleaning brush may be used to sweep off the manure when it has been carried outside the hopper. This type of feed is not reliable with manure that is at all damp or lumpy.

Agitator feed. The roller may be replaced by an agitator which pushes the manure to-and-fro over a number of adjustable holes in the bottom of the hopper. This is a simple and efficient type for sowing heavy fertilisers which are in good condition.

Endless Chain feed. An endless chain, with finger projections, pushes manure through slots in the bottom of the hopper. Disadvantages are stretching and wearing of the chain and a tendency to irregular distribution when the fertiliser is lumpy.

Reciprocating Plate feed. The bottom of the hopper consists of two slotted plates with the holes not opposite one another. A third slotted plate is caused to slide in between. Sowing rate is controlled by the speed of reciprocation of the moving plate and by the distance it travels. If the plates are regularly removed and cleaned after use, this type of distributor is generally satisfactory.

Star Wheel feed. A number of star or finger wheels rotate in the bottom of the hopper, and push the manure through slots of variable size. This type of feed is commonly used in conjunction with an internal force-feed grain mechanism in combined grain and fertiliser drills.

Revolving Plate feed. Saucer-shaped discs are mounted along the bottom of the hopper and driven by bevel gearing. As they rotate, a layer of manure is carried to the outside of the hopper, where it is broadcast by fingers on a high-speed shaft. Advantages of this type are that it can handle almost any type or condition of manure. Distribution is good, and the saucers are fairly easy to clean.

Conveyor-and-brush feed. The bottom of the hopper is formed by an endless canvas belt which moves slowly to the rear and takes a layer of manure to the outside, where it is swept off by a high-speed cylindrical brush. This type is made of non-metallic materials which do not corrode.

Spinning Disc Delivery. A popular distributor has a hopper of truncated cone shape, from which the manure is fed on to a rotating disc. The discs throw the fertiliser over a fairly wide strip. When correctly adjusted good machines of this type work well in calm weather, but distribution is somewhat irregular in windy weather. The hopper is frequently mounted on the tractor's three-point linkage and driven from the tractor p.t.o. Such machines have a high working rate and are particularly useful for applying light top dressings to corn and grassland. A pair of contra-rotating discs may be used.

It is now becoming fairly common to attach a fertiliser-distributing mechanism at the rear of a lorry or trailer on which a large supply of manure can be carried. Some of these outfits are trailer machines which are driven from their own wheels, while others are mounted directly on the vehicle and take their drive by chain or gearing from the vehicle wheel.

Combined Grain and Fertiliser Drills. Combined grain and fertiliser drills are now commonly used for corn crops which require a dressing of phosphatic or compound fertiliser. Most combined drills sow the corn and fertiliser down the same seed-tube, and are fitted with single disc coulters (Fig. 25). Excellent results have been obtained throughout Britain from phosphatic manures applied to corn with the seed in such combined drills. Some injury to germination may occur if any considerable quantity of potassic or nitrogenous fertiliser is placed in close contact with spring-sown crops, especially if a period of dry weather follows drilling. Some crops, such as peas, cannot tolerate fertilisers close to the seed, and such crops should be drilled either through ordinary drills, or, better, by means of fertiliser placement attachments which deliver the fertiliser about 2 in. to one side of the row and at about the level of the seed.

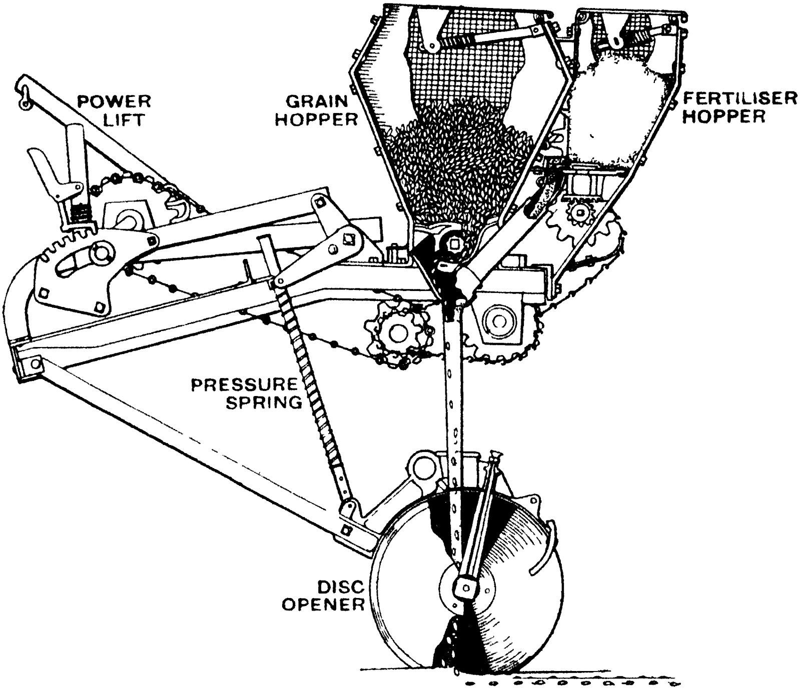


Fig. 25.—Mechanism of Combined Corn and Fertiliser Drill (M.M.).
Grain and fertiliser are in separate hoppers but are delivered down the same spout.

One of the chief faults of the combined drill is the difficulty of cleaning it out effectively, and the harm that results when it is not thoroughly cleaned. It should be emphasised that careful attention to cleaning is essential, and that lack of it causes unsatisfactory work and heavy repair bills.

Farmyard Manure Distributors. The need to be able to handle distribution of farmyard manure effectively and expeditiously with a limited labour force has led many British farmers to equip themselves with mechanical loaders and spreaders. The hydraulically operated tractor loader is a sturdy and fairly inexpensive device which has many other uses, and though several types of loader are available, the hydraulic tractor loader is preferred by most farmers. When this is used in conjunction with an easily-hitched trailer-type spreader, one man can, in reasonable working conditions, load and spread just over 3 tons per hour in a field 600 yards away from the yard. Alternatively, a tractor loader that does nothing else can keep busy a pair of spreaders working fairly near to it, or more spreaders or trailers working over a long distance. Another type of loader comprising an engine-driven cable-operated fork, with an endless conveyor, can work in restricted places such as in boxes. This requires two men for its operation.

The normal type of farmyard manure spreader consists essentially of a trailer with a slatted conveyor running along the bottom towards the rear, together with a shredding and spreading mechanism that throws the manure out at the back (Plate X).

The mechanisms may be either driven from the land wheels or by the tractor's power take-off. P.T.O.-driven machines are preferable where very heavy dressings need to be applied, and where the going is difficult, as on hillsides or slippery land. The p.t.o.-driven type does not fit in well with the one-man system of operation, since hitching up the spreader to the tractor after loading is a time-wasting and often difficult operation. A steady increase in mechanisation in this sphere may therefore be expected.

HAY-MAKING MACHINERY

The Mower. The grass mower, which is used for cutting hay crops, has a cutting mechanism consisting of a finger-bar in which a steel knife, made up of triangular sections, reciprocates at high speed. The cutter bar is flexibly mounted, so that it can lie close to the ground and conform to the irregularities of the surface. The knife may be driven by p.t.o. or from the land wheels, which drive via a simple gear-train, in which the speed is increased, to a crankshaft and connecting rod. The throw of the crank is normally 3 in. The fingers on the cutter bar are set 3 in. apart, and the knife sections are 3 in. wide at the base. The cutting action is like that of a pair of scissors, the reciprocating knife representing one blade and the stationary ledger plates on the fingers the other. For clean cutting the following conditions are necessary : (*a*) each knife section must move precisely from the centre of one finger to the centre of the next ; (*b*) the knife must have a slight lead at the outer end, so that it runs square to the work when actually cutting a heavy crop ; (*c*) the cutter bar must be straight and the fingers in line, so that the knife slides evenly over the ledger-plates ; (*d*) the knife sections must be sharp ; (*e*) the edges of the ledger plates on which the knives slide must not be rounded ; (*f*) the malleable clips which press the knife sections on to the ledger plates should be adjusted to ensure that the knives press very gently and evenly on the ledger plates along the whole length of the bar.

The cutter bar is carried on two shoes, the outer shoe carrying a divider and swath-board, and sometimes a small wheel for easy adjustment of the height of cut, and the inner shoe carrying a bearing on which the knife-head slides. The inner shoe also has attached to it the drag link and lifting mechanism. The lifting mechanism may generally be operated by either hand or foot levers ; and a further lever controls the " pitch " of the cutter bar, permitting close cutting when the ground is smooth, or elevation of the fingers where close cutting is undesirable (Fig. 26: Plate XI).

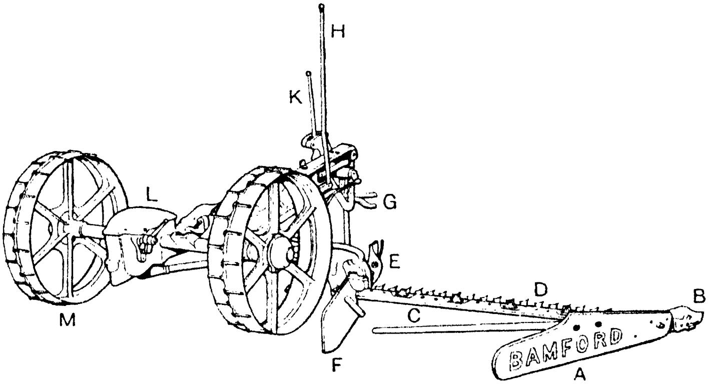


FIG. 26.—TRACTOR TRAILER MOWER.

A, outer track board and grass stick. B, offside (or divider) shoe. C, finger bar. D, fingers. E, inner (or main) shoe. F, inner track board. G, drawbar. H, lifting lever (self-locking). K, tipping lever. L, gear-box. M, travelling-wheels.

Mowing is now almost universally done by tractor, and an average rate of work using a 5 ft. cutter bar is about 1 acre per hour, though much higher rates of work can be attained in good conditions. The tractor is a much more satisfactory form of power for this work than horses, and to get the best results tractor mowers should be employed. Tractor trailer mowers are frequently exactly like specially strong and heavy horse mowers, taking the drive from the travelling wheels ; but machines driven from the power take-off are now more widely used. While some of the power-driven mowers are similar to horse machines apart from the drive, some of the best outfits have the cutter bar carried directly on the tractor, being mounted either at the side of the tractor or close up to the rear wheels on the 3-point linkage. The cutter bar on such machines can usefully be 5 to 6 ft. long where the land is level, and cutting can be carried on at high speed. The advantage of a power drive is that the speed of the knife can be kept up in heavy work, while the forward speed is cut down by engaging a low gear.

The Tedder. When a heavy crop of hay is cut by mower, the swath lies dense and compact, and it is advisable to lighten it up so that sun and wind can penetrate it. This operation should be carried out very soon after mowing, so that drying of the whole swath proceeds uniformly. Tedders are rotary forking machines which are designed primarily for this first operation. They are now usually p.t.o.-driven. Many modern machines are of the forward-action type in which the tines rotate in the opposite direction to the wheels and carry the hay over the cylinder beneath a curved hood. The back-action type tends to be somewhat gentler in its action, but some models have the disadvantage that the hay is less effectively controlled as it leaves the machine (Plate XI).

For a long time the development of tedders was neglected by manufacturers because farmers thought that such machines stripped off too many leaves. This can, indeed, happen if tedders are used too late in the haymaking operation, after the leaves have become brittle. If, however, treatment is begun early, the whole crop dries more uniformly, and can be effectively teased out without losing its leaves.

Swath-Turners and Side-Delivery Rakes. Swath-turners are designed to turn swaths or windrows gently, and to move them sideways slightly during the operation. This often has the effect of turning the hay on to dry ground, in addition to exposing the lower part of the swath to the action of sun and wind.

There are many types of swath turner, most of which can also be used as side-delivery rakes. The rotating-head type has two or three sets of curved spring-steel tines which rotate and gently roll the swath over to one side as the machine advances. The heads may be wheel-driven or p.t.o.-operated. This type, which has a gentle action, can be used as a collector by making adjacent heads rotate in opposite directions.

The inclined rake-bar machine usually has four horizontal bars attached to a pair of discs by a linkage which keeps them horizontal. The machine acts as a swath turner if the centre section of each rake-bar is removed.

The finger-wheel type has a number of ground-driven wheels mounted obliquely on a light frame so that they can be set so as just to touch the ground. They are rotated by their contact with the ground and crop (Plate XI). The machine is operated at a high forward speed, and is a most effective side rake for use in front of a pick-up baler on fairly level land. The finger-wheel machine is very suitable for mounting on the tractor's 3-point linkage, and is an ideal complement to a good tedder or more drastic swath-treatment machines such as crimpers and roller crushers.

Roller Crushers and Crimpers. If the hay swath is effectively bruised in a roller crusher or crimper within a short time of cutting, the drying rate in good weather conditions can be considerably faster than that of swaths that are only tedded. As a general rule, one drastic bruising treatment is carried out immediately after cutting, and thereafter a tedder or swath-turner is used according to the condition of the crop (Plate XII).

Another method of applying drastic swath treatment is to use a flail forage harvester, either for cutting the crop or for the first swath treatment. If a forage harvester is so used it is essential to avoid chaffing, otherwise much of the crop may be lost during subsequent operations. This requires a low rotor speed, high forward speed, and a wide clearance between the flails and the sole-plate of the machine.

The Hay Sweep. In conditions where the crop is to be stacked in the field it is often advantageous to use a sweep. The sweep consists of a number of wooden teeth about 10 ft. long, set about 1 ft. apart in a frame and arranged to be pushed with the points of the teeth projecting forwards. The sweep may be propelled by a pair of horses, a tractor, or a powerful old car, the two latter methods being preferred. Hay may be picked up from cocks or windrows. With a sweep mounted at the front of a tractor or old car the work may be done very rapidly, and full advantage taken of periods of favourable weather. Sweeps may be conveniently used in conjunction with either an elevator, a stacker or a stationary baler.

The Elevator. The elevator is a device used for stacking hay, corn or straw. It operates by means of an endless conveyor which runs upwards along an inclined trough. The conveyor consists of a chain with wooden cross-slats and up-standing tines. The tines pick up the hay or straw from the hopper at the bottom and deliver it on to the stack. The trough is adjustable to suit the height of the stack. The conveyor is generally driven by a small internal-combustion engine, which is often mounted on the four-wheeled chassis on which the elevator is transported. When used with a threshing machine the elevator may be driven from a pulley on the threshing box.

The Horse Fork. The horse fork is a simple crane carrying a hay grab in the form of a grapple or a harpoon. The crane usually consists of a swinging boom attached to a vertical guyed mast. The grab is lowered on to a cart or to a heap of hay left by a sweep on the ground. The teeth of the grab are firmly pushed into the hay and the fork is then raised by a system of ropes and pulleys, operated by a horse. As the horse is led away from the stack it pulls on a rope and raises the grab. The grab is then swung over the stack, and the load is released by pulling on a cord.

The Overshot Stacker. The overshot stacker consists of a framework like a sweep, carried on two telescopic arms that can be raised by a system of ropes and pulleys. With the cradle of the stacker resting flat on the ground, a sweep-load of hay is pushed on to it and deposited there. The rope which operates the stacker is pulled by a horse, a tractor, an old car, or by an engine and friction hoist. The arms of the cradle extend as they rise, and eventually pass right over the vertical position, throwing the hay over backwards on to the stack. Along with a sweep or sweeps, use of the overshot stacker results in very fast work.

Stationary and Pick-up Balers. A method of haymaking which has rapidly developed in Britain in recent years has been the baling of hay direct from the field. Both stationary and " pick-up " balers are used, the former usually in conjunction with a sweep.

The pick-up baler travels along the windrow (Plate XII). With either machine, baling can usually be done a little before the hay is fit to stack.

Several types of baler are used, ranging from heavy machines which make large, tight, hand-wired bales to lighter machines which make small, looser bales that are automatically tied by twine. The latter type has now almost entirely superseded the wire baler for general farm use. With the self-tying pick-up type, a mower and a combined swath turner and side rake, the whole process of hay-making can be efficiently mechanised.

Machinery for Cutting and Collecting Grass and Forage Crops. Silage-making and grass drying have both been facilitated by the introduction of machines specially designed for collecting grass and forage crops. An early machine was a cutter-loader called the " Cutlift ", which cuts and loads the crop in one operation. This machine is adaptable for use in a variety of crops ranging from short grass to kale. The green-crop loader is a machine which will collect from the swath or windrow after the crop has been cut by an ordinary mower. A wide range of green-crop loaders was developed, but most soon became obsolete. These machines are used in much the same way as ordinary hay-loaders, but they are more strongly constructed and employ a variety of mechanisms for picking up the green crop from the ground, and for delivering it on to the vehicle. Some green-crop loaders are of a general-purpose type, suitable for use in either hay or silage, or for grass drying.

One of the simplest and cheapest ways of mechanising the collection of green crops for silage, especially where it is possible to make the silage in or near the field, is by use of a tractor-mounted buck-rake (Plate X). The chief limitations of this device are that the buck-rake will not make a clean job in crops much less than 10 in. long, and that it is suitable only for short hauls.

For longer hauls it is possible to mount the buck-rake on a hydraulic tractor front loader and use the outfit for loading trailers ; but this system is only suitable if the land is reasonably level.

HARVESTING MACHINERY

The Forage Harvester. A forage harvester is a machine which either cuts the standing crop or picks up a swath or windrow, chops or lacerates it, and delivers it into a trailer running alongside or pulled behind the machine. There are many distinct types and, in recent years, machines of the simpler and cheaper kinds have been rapidly adopted for silage making in Britain.

The widely-used flail type of machine has a large number of knives mounted on swinging arms attached to a horizontal rotor. This rotates in the opposite direction to the wheels. A hood covers the knives, and the cut crop is caught up between this and the knives, and partly blown, partly thrown into a trailer towed behind. This type of machine can work equally well on either standing or previously cut crops (Plate XIV). Another simple type has a pair of horizontal high-speed four-bladed rotating knives to make a cut about

4 ft. 6 in. wide. The cut crop passes to a lacerating mechanism, which blows it directly into a vehicle.

A slightly more complex machine has a pick-up mechanism which delivers the previously cut crop to a chopping cylinder fitted with helical blades.

Complex types of forage harvesters which chop crops finely are manufactured, but they tend at present to be more costly than the simple types already mentioned. They are necessary if the silage is to be conserved in silos and fed to the stock by mechanical means, and are particularly suitable for crops such as maize.

The Binder. The binder is one of the more complicated and expensive of farm machines. The drive is taken from the bull-wheel or travelling wheel, and passes by way of chains and toothed gears to the cutting and binding mechanism. The cutting mechanism does not differ in essentials from that of the mower, consisting of a knife reciprocating between a row of fingers. The main difference from the mower is that the speed of the knife is lower and the throw of the crank is 6 in., so that the knife sections pass over two spaces between fingers. The reel (sails) gathers the crop on to the knife and is adjusted to cause the corn to fall uniformly on the platform canvas after being cut. A system of endless canvases (one platform canvas and two elevator canvases) takes the corn up over the travelling wheel to the binder deck, where the binding mechanism forms the sheaves and automatically ties them.

Adjustments. The following binder adjustments may be made from the driver's seat, and some of them need constant attention in variable crops.

(1) The reel may be adjusted both horizontally and vertically to assist in getting the corn laid evenly on the platform canvas.

(2) The pitch of the platform may be adjusted to control the length of cut and the way in which the corn falls on the platform. Height of the stubble is also varied by raising or lowering the main wheel and the grain wheel in the binder frame.

(3) A lever controls the position in which the sheaf is tied. The band should be kept approximately in the middle.

(4) The position of the buttor can be varied to suit long or short crops.

The size and tightness of the sheaves may be adjusted by varying respectively (*a*) the position of the trip lever and (*b*) the tension on the trip spring.

The *Sheaf Carrier* is a device which is used for preventing obstruction at the corners of the work and for dropping sheaves into windrows for ease of stooking where the crop is very thin. It can be used at will to carry five to six sheaves, being operated by a foot control.

Pulling a 6-ft. cut binder is hard work for a three-horse team, and the tractor is now generally used for this work. The tractor gives a steadier pull and is a more satisfactory form of power in every way. On soft ground, however, binders which take their drive from the bull wheel still sometimes fail owing to slipping of this wheel. The remedy is, of course, a drive from the tractor power take-off, and all modern tractor machines are of the power-drive type. Power-driven binders deal much better with dense and tangled crops. They may be had with cutter bars 8 to 10 ft. wide—though there are few farms where full advantage can be taken of machines as wide as 10 ft. cut.

Even with a narrow cut the binder is too wide to transport in the working position along the highway. Auxiliary transport wheels are provided, and these enable the machine to be pulled from one side.

THRESHING MACHINES

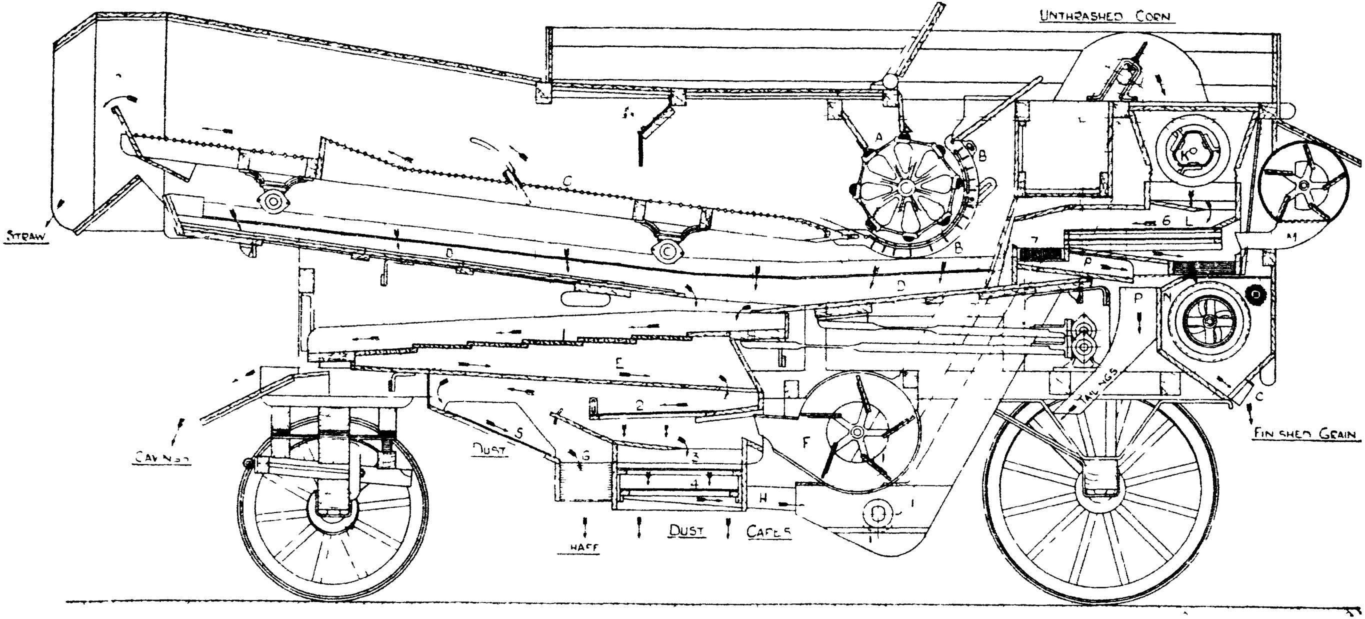
The modern thresher is a complicated and expensive machine. It threshes the grain from the straw, winnows away the chaff, grades the grain according to size, and delivers the straw, the chaff, the cavings (broken pieces of straw, leaves, etc.), weed seeds and the corn from different parts of the machine (Fig. 27).

On small farms, threshing is usually done by contractors, who supply a complete outfit, consisting of tractor, threshing drum, and either elevator, straw trusser, baler or chaff-cutter. Two men usually travel with such an outfit, one being responsible for adjustments to the machine and seeing that the work is carried out efficiently, and the other feeding the corn into the drum. Now that most of the larger farms have their own tractor, and also an elevator or baler, a steadily increasing number find it worth while to have their own threshing machine or combine harvester, so that the work may be done at any convenient time.

Before work is commenced the machine must be set absolutely level, so that the corn is properly spread out over the riddles. The band tying each sheaf is cut, and the corn is fed loose into the thresher, between the drum and concave. On most machines a self-feeder is provided to assist in this operation ; and this simple device is so useful that every machine should be fitted with one. The *drum*, which rotates at about 1,000 r.p.m., carries a number of ribbed steel bars called *beaters*, which rub out the grain by beating the ears against a quarter-circle grid called the *concave*. The clearance between drum and concave can be adjusted to suit different kinds of grain and different threshing conditions. For example, beans require a very wide setting, while wheat which is damp requires a close setting so that the ears receive a thorough rubbing.

Most of the grain falls through the bars of the concave, while the straw moves forward along the shakers until it passes out of the end of the machine. In the shaking process, all grain should fall through on to a collecting board, whence it passes, with the grain from the concave, on to the *cavings riddle*. Oscillation of the cavings riddle carries the cavings forward and delivers them at the end of the machine, beneath the straw. The grain and chaff pass through the cavings riddle on to another collecting board, whence they pass to the first dressing shoe.

The *dressing shoe* consists of a number of oscillating riddles and a blast of air created by a fan. As the grain falls on to the upper riddle, the chaff is blown out, the blast being adjusted so that no



A, drum
B, concave
C, straw shakers
D, top shoe
E, bottom shoe
F, first dresser fan
G, chaff spout
H, corn spout

I, elevator cups
K, awner and smutter.
L, second dresser.
M, second dresser fan
N, rotary separating screen
O, corn sacking outlets.
P, tailings spout.

RIDDLES
1, cavings riddle.
2, wind riddle.
3, capes riddle.
4, seed sieve.
5, chaff sieve
6, second dresser riddles
7, tailings riddle.

[*William Foster and Co. Ltd. Lincoln*

FIG. 27.—SECTION OF A THRESHING MACHINE.

good corn is blown away. The chaff either falls in a heap on the floor below the machine or passes to a chaff sifting and bagging device. The upper sieve removes the " chobs " (unthreshed pieces of ear, beans in wheat, and so on) and drops them to one side. The small weed seeds pass right through the sieves on to the ground. Riddles with holes about $\frac{1}{4}$ in. in diameter are generally used in the first dressing shoe for wheat, while those required for barley are $\frac{5}{16}$-in. to $\frac{3}{8}$-in. and those for oats about $\frac{1}{2}$-in. mesh.

The corn is delivered from the seed riddle to the scoop of an elevator, consisting of metal buckets on an endless band. The buckets take the corn to the top of the machine and deliver it either direct to the corn spouts or through part or all of the awner and chobber and then to the second dressing shoe.

The *awner and chobber* consists of knives and bars which rotate on a fast-moving spindle inside a metal housing. The knives cut off the awns of barley, and the bars of the chobber rub off any chaff that is still adhering to the grain. The rate at which the corn passes through the awner and chobber, and the degree of rubbing, are adjustable ; and it is possible to by-pass all or part of the mechanism.

The *second dressing shoe*, which consists of a fan and riddles similar to those of the first shoe, blows away the chaff and awns. The cleaned grain then passes to the *rotary screen*, which grades it into samples of different sizes. The screen has the wires spaced close together at the end at which the grain enters, and farther apart as it advances along the inside of the screen. The small and split grains pass through early, and the large ones pass right along and drop out of the far end. The screen may be adjusted by turning a handle at the end of the spindle. Two or three samples are generally made, and the " head " corn is normally fit to market just as it comes from the machine. A sectional view of a threshing machine is given in Fig. 27.

The output of a thresher depends largely on the size of the drum and the rate at which the machine is fed. The most common size of drum is 4 ft. 6 in. wide and 22 in. in diameter. Such a machine can be driven by a tractor developing about 20 B.H.P., and is capable of threshing up to about 2 tons of corn per hour. The labour force required is reduced if the machine is equipped with a straw trusser, and blowers for dealing with the chaff and cavings.

COMBINE HARVESTERS

The combine harvester cuts and threshes in one operation, and consists essentially of a cutting mechanism similar to that of a binder, together with a threshing mechanism like that of a stationary thresher. The main types of combines are (1) small machines which are driven from the tractor power take-off ; (2) machines which are pulled by a tractor but have the threshing mechanism driven by an independent engine mounted on the machine ; and, (3) self-propelled machines (Plate XIII). The self-propelled type, which has the cutter bar at the front, has many advantages over other types, and is popular on large farms or for contract work. The main disadvantage of this type is the high cost. Engine-driven trailed machines have marked advantages over machines driven from the power take-off, especially on undulating land ; but the latter have the merit of relative cheapness.

Combine harvesters can usually leave a stubble from about 3 in. to 24 in. long in an upstanding crop ; and with crops which are not laid it is usually advisable to cut a fairly long stubble, so as to ease the work of the threshing mechanism and to keep above the worst of the weeds. Where it is necessary to cut very low the speed of working is reduced, since threshing capacity is the limiting factor.

The threshing drum in combines used in Britain is usually of the beater type, similar to that used in stationary threshers. There are, however, two other types of drum used in combines, viz. the *peg-tooth* drum similar to that commonly used on stationary American threshers, and a *flail type* similar to the beater drum but of lighter construction. The beater drum seems as well suited as any to British conditions. The principles of setting the drum and concave are the same as with the stationary thresher ; but it is sometimes the drum axis which is movable, and not the concave.

The sieves are often of a louvred type. The fans need frequent adjustment to ensure that the grain is cleaned but that none is blown away with the chaff. There is a device for returning to the threshing drum any pieces of ear which have not been effectively threshed. Some combines separate and collect the weed seeds, but others either scatter the very small seeds or deliver them mixed with the grain.

Combines may be equipped either with a platform and spouts for bagging off the grain, or with a grain tank. The former equipment is preferable where adequate facilities for receiving and handling grain in bulk are not readily available, but where an efficient grain conditioning and storage plant is installed the bulk-handling system is usually preferable. It requires the provision of suitable grain-tight trailers that can be easily emptied into a receiving hopper. The usual method of transport is now to employ 3-ton hydraulic tipping trailers, which are also suitable for many other kinds of farm transport work.

Where a bagger type combine is used it pays to arrange to drop the bags in windrows, so that they are easily picked up, or to transfer them directly to trailers standing at convenient places in the field.

Where both combine and binder are used it is advisable to use the combine on the lighter and cleaner crops. Weeds reduce output by clogging the screens and shakers. If weedy crops must be combined it is sometimes advisable to use the windrow method, whereby the corn is first cut and windrowed, and is later picked up and threshed after some drying has taken place. Laid crops which are clean can often be satisfactorily dealt with if lifters are fitted. Wheat and barley should be combined in preference to oats.

All grain must be dead ripe before being combined. Wheat needs to be left ten days to a fortnight after it is fit for the binder. There is, of course, a risk of oats " shattering " and of barley " necking " when the crops are left to ripen.

The chief problems connected with use of the combine harvester in Britain are drying of the grain where necessary, and handling of the straw after the machine. It is almost essential in most parts of Britain to have available drying facilities for dealing with grain that is too damp for safe storage, and the main farm drying and storage systems are briefly discussed on pages 90 to 96. Grain cannot be safely stored in bulk if the moisture content exceeds about 14 per cent and while it is often possible to combine corn as dry as this, some samples may contain 20 per cent or more of moisture. It is therefore necessary in Britain to have drying facilities available if the combine is to be used to best advantage. Farm grain driers vary from simple, home-made machines to elaborate and expensive ones.

Where the straw has to be collected after combining, sweeps or pick-up balers are commonly used. The cost of harvesting by combine is much less than that of harvesting and threshing by the usual methods if collection of the straw is not necessary. Where the straw has to be collected separately, however, there is usually not a great difference in total cost. An advantage of the combine method which is more important than the cost difference is the fact that the need for large labour gangs at harvest and threshing time is eliminated.

Trussing devices for handling the straw as it comes from the machine are now available for several makes of combine, and this method of straw handling is very suitable for many British farms. Where the straw contains much greenstuff it is usually advantageous to leave the bales out for a day or two in fine weather, but otherwise they may be carted and stacked immediately.

ROOT HARVESTING MACHINERY

Potato Diggers. Potatoes may be lifted by a simple potato-raising plough, a potato spinner or an elevator-type potato digger.

The Potato Plough. The plough is similar to the common ridging plough, but has wrought iron raising prongs instead of the double mould-boards. The potato-raising and ridging bodies are often interchangeable on the same implement. The plough lifts the potatoes without bruising, and has no moving parts. Its disadvantage is that it leaves many of the potatoes either partially or completely buried, and very thorough harrowing is necessary, while picking is difficult. When a potato-raising body is fixed to a tractor tool-bar and drawn fairly fast, results can be better than with a horse-drawn implement.

The Spinner. The potato spinner exists in many forms. On one type the main spinner rotates about an almost vertical axis, just behind a broad share which runs beneath the potatoes, while in another type the spinner axis is horizontal. Tractors are now commonly used for operating potato spinners, and strong self-lift machines have been developed. A neat machine is the unit-principle power-driven type, which is carried on the rear of the tractor and is raised by the hydraulic lift (Plate XV).

The Elevator Digger. In the United States the elevator digger is almost invariably used, and this type of machine is now quite common in Britain. It consists essentially of a broad share, followed by an inclined, slatted elevator (Plate XV). The elevator is shaken to a variable degree by agitator sprockets, and the potatoes are shaken free from soil and dropped to the ground in a narrow row. The elevator digger makes picking easy, and is now widely used in the main potato-growing districts. Its chief disadvantages are that it will not work when the land is wet, and it may bruise the potatoes badly, especially if the crop comes out clean ; while most machines of this type require frequent repair.

Many complete potato harvesters, which dig and riddle the tubers and deliver them up a conveyor and directly into a cart, have been developed (Plate XV).

Sugar Beet Lifters. Lifting sugar beet by hand is rapidly becoming obsolete. Where hand methods are employed, the roots are usually loosened by a tractor-drawn lifter before being knocked and topped by hand. Two main types of lifter are used for this work. One has a vertical knife with a wedge-shaped share at the bottom of the blade. The knife is run alongside the roots, and the share loosens them by pushing them upwards. The other main type has a pair of strong curved arms with a share at the bottom of each. The shares pass below the row of beet and raise the roots between them. Multi-row loosencrs pulled by tractor are now used.

In recent years much effort has been devoted to the development of sugar-beet harvesters designed to perform one or more of the operations hitherto carried out by manual labour. This has resulted in the development of a very wide range of harvesters which top the beet, lift and clean the roots, and load the clean roots into a trailer. These harvesters are now very widely and successfully used, but their capital cost is such that they are beyond the reach of most growers of small acreages, except through the medium of contractors. Fortunately, development work has not been confined to expensive harvesters, and there are also available machines which carry out separately all of the following operations :

1. Topping of one to four rows.
2. Lifting and cleaning one or two rows.
3. Topping one row and loading the tops.
4. Lifting and cleaning one or two rows and loading the beet.

In addition, machines which top the beet, load the tops, lift and clean the roots and either load them or dump them at the end of the field, have been developed.

Modern harvesters are so successful from both technical and economic aspects that few beet-growers can now afford to do this job by hand (Plate XVI).

FIELD CROP SPRAYERS

In recent years, spraying for weed control has become a commonplace operation on almost all farms where corn crops are grown (see p. 211). This widespread adoption of a new husbandry practice has been made possible by the development of new chemical sprays which can be effectively applied in the form of a fine mist at very low rates, e.g. down to 10 gallons per acre, and has been aided by the production of cheap and simple machines designed to apply the solutions. Spraying machines for field crops may be broadly classified into the following groups :

1. Low Volume (10–40 gallons per acre). Such sprayers are

designed primarily for applying true solutions such as MCPA and 2,4-D. They are almost invariably tractor-mounted, and have a small tank and a simple p.t.o.-driven pump, usually of the gear type. The machine works at low pressures (normally 30–40 lb. per square inch) and employs simple fan jets.

2. Low/Medium Volume (10–60 gallons per acre). The tank usually has a capacity of 50–100 gallons, and the larger capacity pump may sometimes be of a type suitable for spraying suspensions. Usually, however, these machines, while capable of handling materials like proprietary potato fungicides for short periods, are unsuitable for spraying "Dinitro" suspensions or Bordeaux mixture. As in low-volume machines, agitation of the fluid in the tank is usually effected by arranging for surplus liquid from the pump to be directed through jets back into the tank.

3. High-Low Volume (10–100 gallons per acre). These machines usually have a tank of capacity 80–250 gallons, and in the larger sizes are trailed machines. The pump is a type (e.g. plunger) capable of handling any sort of spray material at pressures ranging up to 150–200 lb. per square inch. A mechanical agitator is used to stir the liquid in the tank. Low-volume applications are handled by using fan jets, while swirl nozzles are usually fitted for high-volume application (Plate XVII).

The simplest and cheapest sprayers cannot be expected to handle effectively a full range of field-crop spray materials, but may be quite suitable for farmers whose chief or only need is to spray corn crops. At the other extreme, a contractor or a farmer who regularly has to spray potatoes or to use "Dinitro" compounds is well advised to buy one of the more expensive machines that are capable of effective high-volume work. Machines of the intermediate (low/medium volume) group can be used to a limited extent for applying suspensions, but there may be difficulties due to insufficient agitation of the liquid, or to the rapid wear of an unsuitable type of pump.

Pneumatic sprayers do not employ hydraulic pumps but distribute the spray by using an air compressor to exert a pressure on the liquid contained in a strong airtight tank. This method is particularly suitable for spraying sulphuric acid, since the spray fluid does not come in contact with the compressor. Another system of spraying is the "atomiser" or air-flow method, whereby the spray is broken up into droplets and carried to its target by a high-speed air blast created by a centrifugal fan. This type is rather expensive in construction, but has the advantage of being able to distribute suspensions fairly effectively at low volume, since it does not depend on the use of small spray nozzles.

Some of the chief operating points to observe in using any sprayer are:

1. Correct dosage. With modern p.t.o.-driven machines this is simply arranged by choosing a set of nozzles of the correct throughput, seeing that the operating pressure is set to that recommended by the manufacturer, and taking care to drive the tractor at the correct speed—usually 4 m.p.h.

2. Avoidance of spray drift. The finely divided spray produced

by low-volume nozzles can easily drift on to neighbouring crops. This may be a serious matter if weed killers are being used. Drift dangers can be minimised by choosing suitable weather and by using more dilute material at a higher application rate.

3. Cleanliness of machine and of water supply. All filters must be used and cleaned regularly, and all parts of the machine should be washed clean immediately after use. When changing over from weed spraying to the spraying of susceptible crops, use of a detergent such as washing soda is advisable.

4. Danger to operators. Some spray materials are very poisonous, and where these materials are used, certain regulations designed to safeguard health and life must be complied with. Fortunately, the "growth-regulating" sprays such as MCPA and 2,4-D are relatively safe to use, and the special safety regulations do not apply to the handling of these less-dangerous materials.

EQUIPMENT FOR IRRIGATION

The starting-point for any scheme of irrigation must, of course, be the availability of a suitable water supply, and the quantity of water needed to do a worthwhile job should not be under-estimated.

It requires 22,650 gallons of water to apply one inch to one acre (this quantity is called 1 acre-inch) ; and during a severe drought it may be necessary to apply 1 inch every 10–14 days in order to secure the best results. Nevertheless, on average, only about 2–6 in. per year are needed for most farm crops, though much more may be applied with advantage in exceptionally dry years.

When a stream is to be used as the source of supply, its flow, or the amount that may be extracted, must be reckoned in dry, summer conditions. Other sources of supply include boreholes, wells, ponds, and artificially constructed reservoirs. In all cases it is advisable to check the legal position concerning water extraction rights, as well as to ensure that the supply is technically suited to the need.

Having cleared the situation concerning water supply, it is advisable next to consider details of the crops to be watered. It is necessary to assess the total acreage to be covered in any one season, and also the extent to which the needs of the crops overlap, so that an estimate can be made of the total area to be covered during 10–14 days in a dry spell. When this is known, the acreage that must be covered in a day is easily reckoned, and knowing the time taken to put on say an inch of rain, the area that must be watered at any one time can be decided. For example, a typical farm plant may cover 1½ acres at a given moment, and may be capable of 3 moves daily. At this rate, 50 acres are covered in about 11 days.

Types of Distribution Equipment. There are three main types of distribution equipment, viz. :

1. Large-diameter rainers,
2. Small to medium diameter rotary sprinklers,
3. Oscillating spray-lines.

Large rainers employ a large nozzle and a high pressure in order to throw part of the water a long distance. This inevitably leads to the production of large drops. Large drops applied at a high rate can do considerable damage to the structure of unprotected soil, and rainers are best suited to crops that provide a full cover, e.g. established grassland and top fruit.

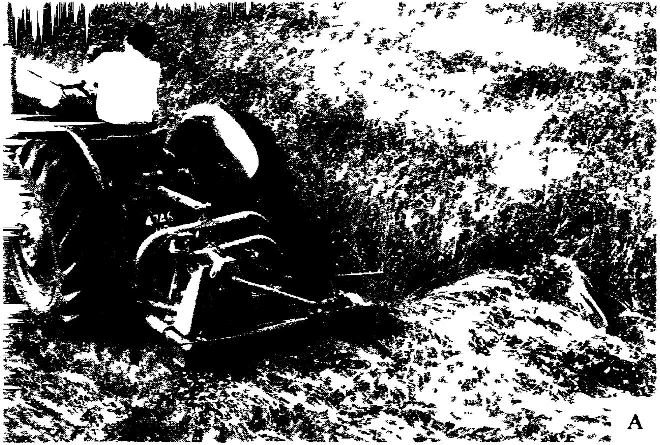
Small-diameter sprinklers are versatile equipment which can be used for a wide range of crops, including vegetables. They operate at a low or moderate pressure, and require less power than rainers. They are arranged to provide a high degree of overlapping, and if used with care they can provide a reasonably uniform distribution (Plate XVII). Application rates can be varied by choice of nozzles to suit the soil and crop conditions. Quick couplings and aluminium sprinkler lines can make moving quick and easy.

Spray-lines, which water rectangular strips, are particularly suited to vegetable cropping. They cost more and take more time to move than rotary sprinklers, but can provide small drops and a uniform distribution suited to the watering of delicate crops such as lettuce.

Pumps. The type of pump and distribution mains employed depend on the source of water and the layout of the fields. Where the water is at a fixed point and the fields are so arranged that the first part of the main is always in more or less the same position, there is much to be said for a permanent pump-house with an electrically driven pump and a buried permanent main. The pump used for distribution is usually a single-stage centrifugal type, as this is cheap to buy and maintain, and is largely self-regulating. A diesel engine may be used where electricity is not easily available. Where, on the other hand, there are several scattered sources of water, it may be preferable to have a mobile engine-driven or tractor pump and a temporary main made of aluminium alloy.

It is necessary to make a careful calculation of the pump capacity needed, and account must be taken of such factors as the difference in levels between the supply and the highest field, and the friction losses in pipes, couplings, etc. It is essential to plan the whole scheme in adequate detail, not forgetting such accessories as a good strainer, the necessary gate valve and pressure gauge near the pump, take-off hydrants, elbows, end stops, and so on. A plan should be made of the best method of working each field, with a view to economising both in capital cost and in the time taken to move the equipment. Time taken for moving varies considerably from farm to farm and from crop to crop. Thus, whereas one man can move 1 acre of sprinkler equipment in about half an hour on short, level grassland, a typical time for moving the same equipment is about 2 man hours, and may be higher in a well-grown potato crop.

The total cost of irrigation varies considerably, according to the capital cost, which may range from under £20 to over £50 per acre, and the amount of use. When account is taken of depreciation and maintenance cost as well as the running cost of all equipment, and allowance is made for the labour involved, a typical cost of applying 1 acre-inch of water by sprinkler equipment is in the region of 50*s*. but may range from about 30*s*. to well over 60*s*., according to the type of plant and the amount of water applied. Thus, the cost of



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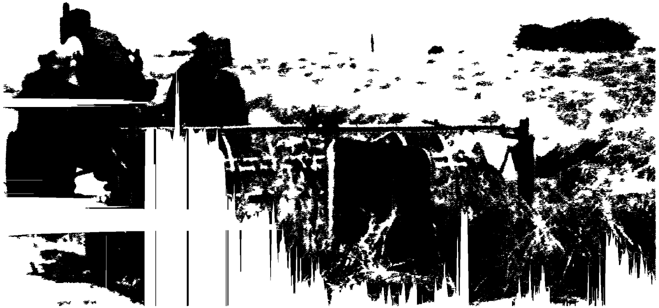

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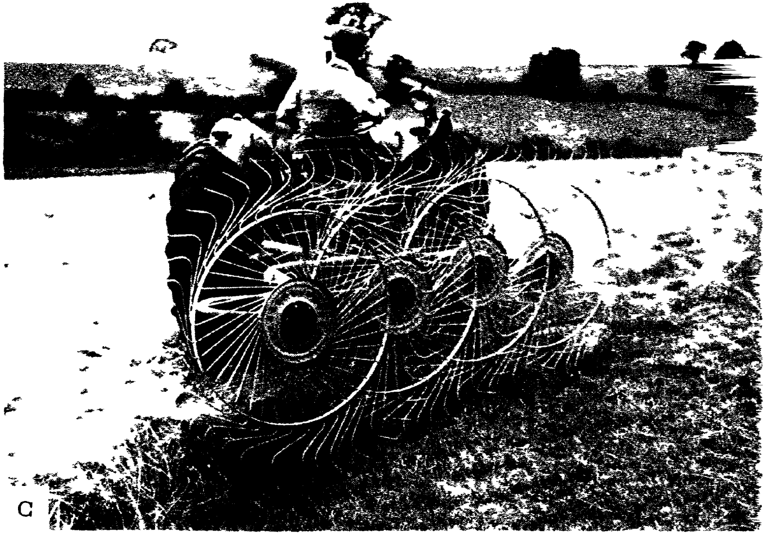

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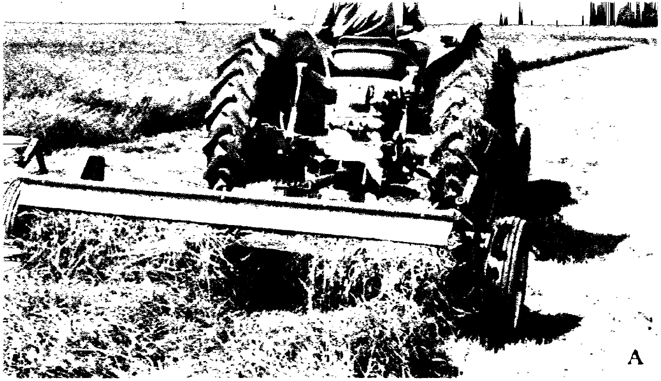
PLATE XI

A Rear mounted Mower

B Hay Tedder (with wind shields)

C Side Rake and Swath Turner (finger-wheel type)



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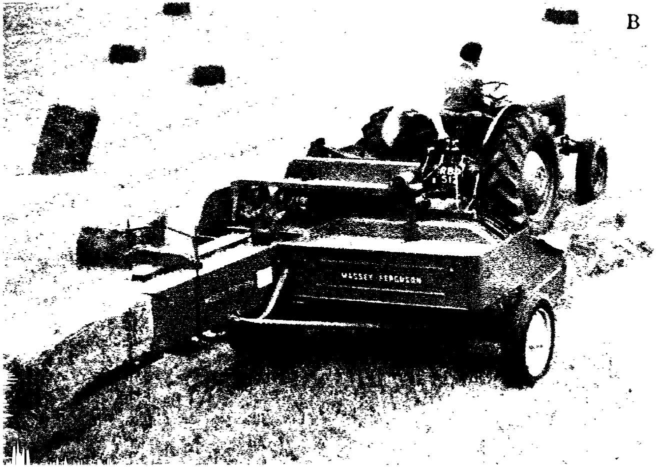

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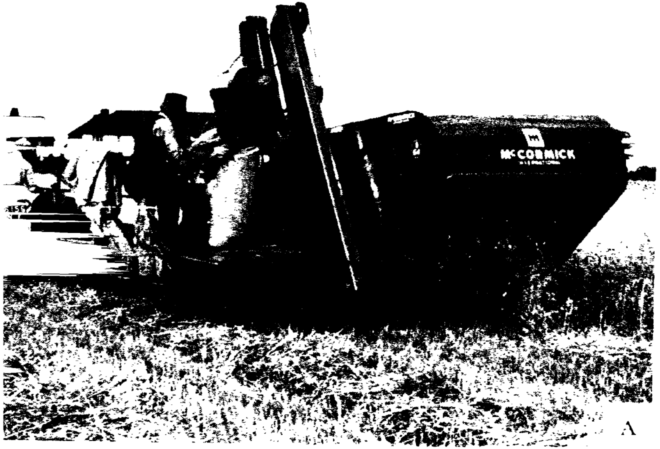
PLATE XII

A. Hay Crimper
B. Pick-up Baler, p.-t.-o. driven, rear view
C. Pick-up Baler, front view



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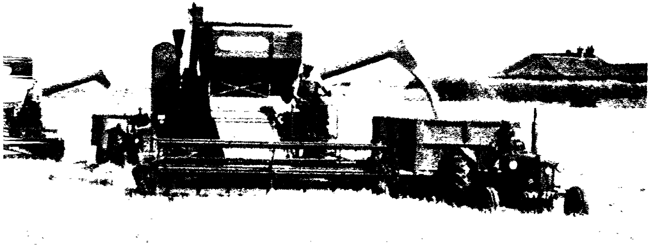
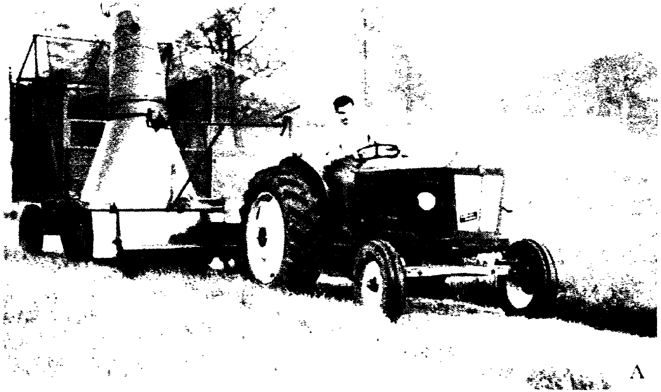


PLATE XIII

A. Combine Harvester, p.-t.-o. driven bagger-type

B. Combine Harvester, self-propelled, with totally shielded external drives and slewing unloader pipe

C. Combine Harvesters, self-propelled tank-type, emptying into trailers alongside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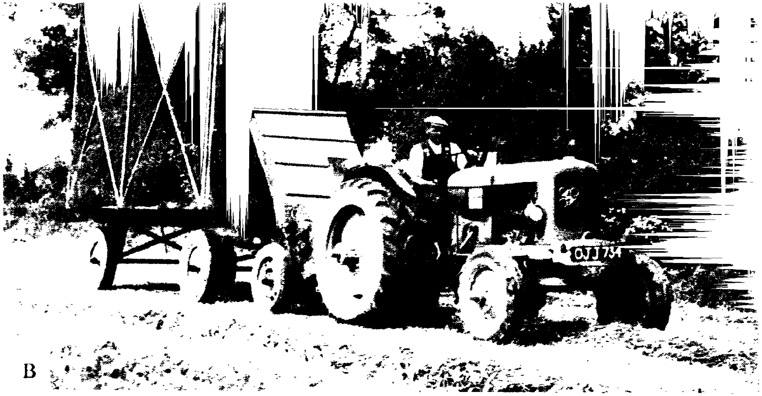
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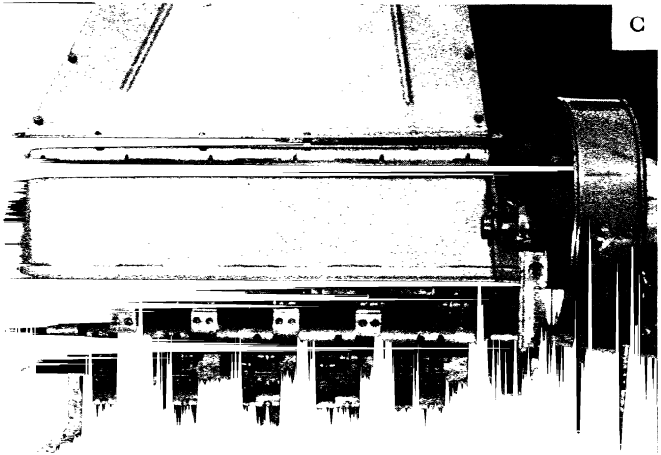
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PLATE XIV

A. Forage Harvester, offset, with Trailer
B. Forage Harvester picking up wilted Silage Material
C. Rotor and Flails of a Forage Harvester

A

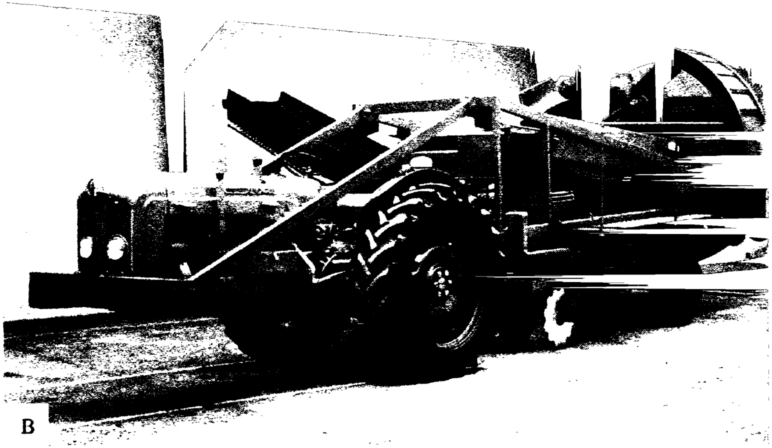

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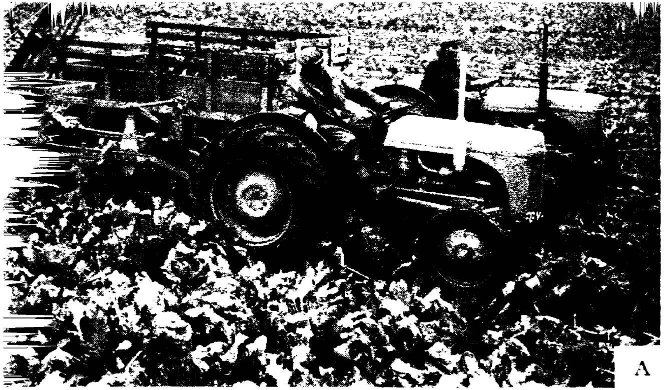
PLATE XV

A. Two-row Elevator Potato Digger

B. Self-propelled 2-row Potato Harvester built round a standard wheeled Tractor

C. Potato Spinner



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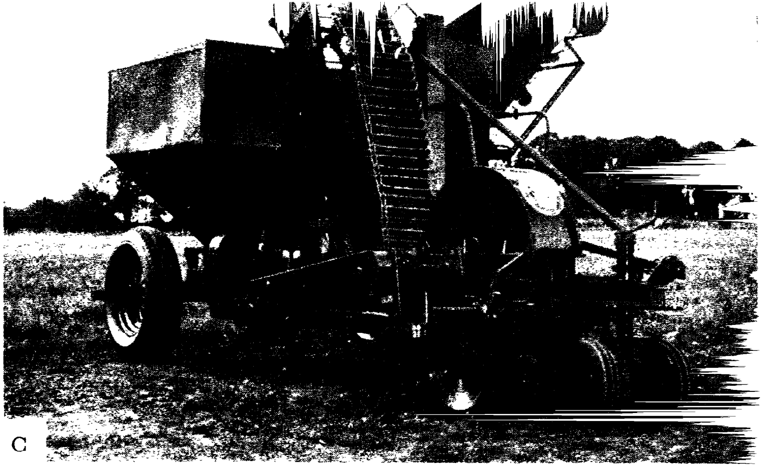

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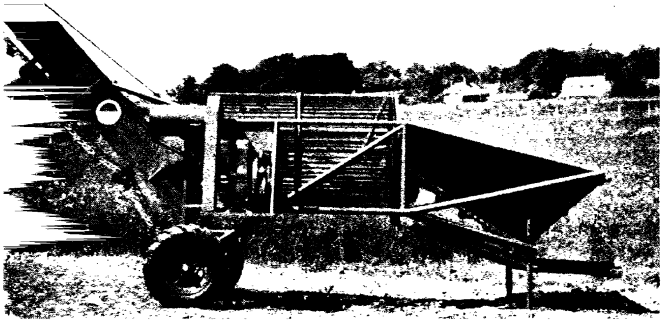

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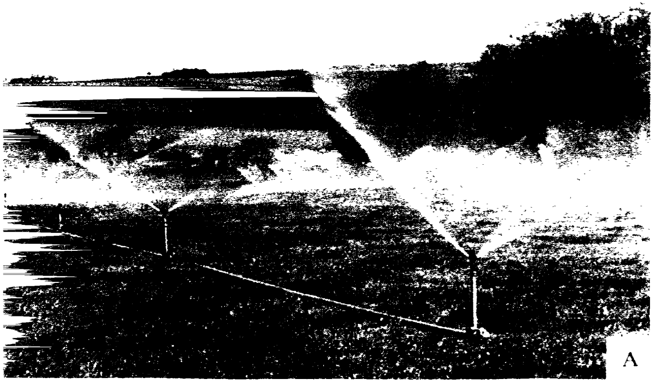
PLATE XVI

A. Beet Harvester
B. Sugar beet Cleaner-Loader
C. Sugar beet Harvester with self-emptying Tank



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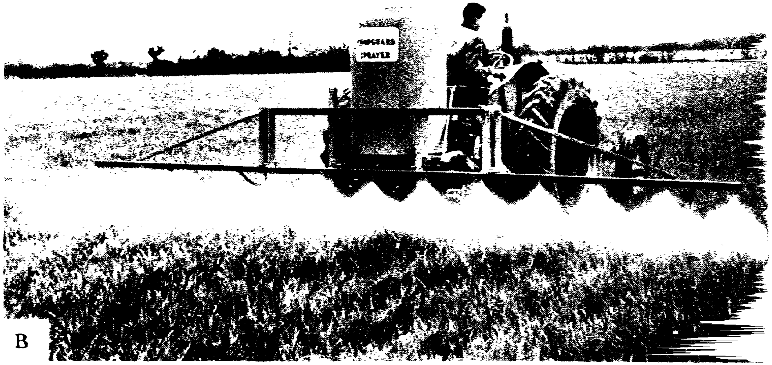

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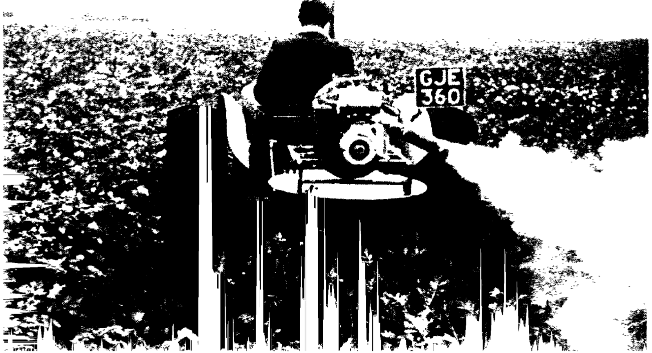
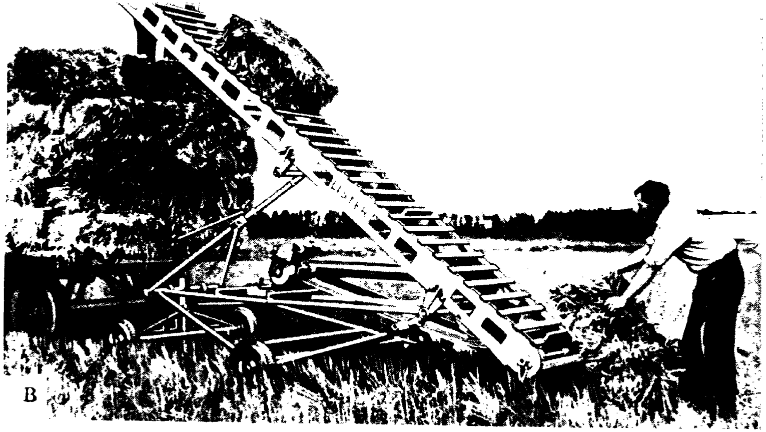


PLATE XVII

A. Sprinkler-type Irrigation Equipment on Grassland
B. General-purpose Crop Sprayer
C. Modern Dusting Machine

A


B

C

PLATE XVIII

A. Mechanical Hedge Cutter
B. General-purpose Elevator
C. Farm Ditcher

applying 3–4 in. to a crop of potatoes or sugar beet may be in the region of £8–12 per acre.

HEDGE CUTTERS

Most tractor hedge cutters fall into two broad classes, viz. : those which employ a circular high-speed cutter and those with a cutter bar of the reciprocating sickle type, similar to that used in a grass mower.

Machines of the circular cutter type usually employ a heavy blade similar to that of a typical wood saw. The saw is usually on an articulated arm and is manœuvred by a number of hydraulic rams. The drive is usually from the p.t.o. through a number of universal joints. Some cutters of this general type are driven by a hydraulic motor, and this effectively gets over the difficulties in the transmission of power to the cutter head. This type of machine is capable of dealing with overgrown hedges, and can cut branches several inches thick. It is somewhat dangerous to operate, and is usually a contractor's machine.

There is a wide variety of machines that use a reciprocating cutter bar (Plate XVIII). One of the most common is mounted on a hydraulic front loader and is operated by an independent engine of about 2 h.p. Many tractor-mounted machines are p.t.o.-operated, and the best of them can tackle growths over an inch thick. The cutter bar is a heavy type with blunt-nosed fingers. Most modern machines are designed for one-man operation, but with some models a second man is needed. There are considerable variations between different makes in such factors as the reach of the machine, ease of operation, and the time taken to put it on the tractor.

For work on hedges that are very difficult of access, there are machines the cutter-bar of which is hand-held. In one type the light cutter-bar is operated by compressed air, and in another by electricity. One machine is driven by a small engine carried on the operator's back. Hand-held machines are for regular trimming of light growths, and have a considerably lower output on straightforward work than typical tractor-mounted machines.

DITCHING MACHINES

A wide range of ditching machines has been developed for use by individual farms. These are generally designed for ditch maintenance, rather than for the kind of ditch construction work that the excavators employed by contractors can undertake. There is, however, no sharp distinction between farmers' and contractors' machines, for developments in the use of the farm tractor's standard hydraulic system have resulted in relatively inexpensive ditchers which can do very effective work in field ditches of the normal size.

The simplest and cheapest type of ditcher is a scoop which is mounted either on the tractor's 3-point linkage or on the arms of a front-loader. In either case the tractor works at right angles to the ditch, drops the bucket into the ditch on the far side, and gradually raises it by the tractor's hydraulics as the tractor moves away from the bank. Disadvantages are that the bucket has a tendency to pull down the near-side bank, and that working conditions are made difficult by the mud that is deposited near the bank (Plate XVIII).

More complex ditchers are operated by two or more external hydraulic cylinders. A boom carrying the bucket pivots on the tractor, and the tractor remains stationary during the digging, lifting, swivelling and emptying operation. A typical machine is operated by three rams, and has the bucket mounted on an articulated boom that pivots on the rear of the tractor. The tractor runs parallel to the ditch and moves forward a few feet at a time. The bucket is usually a simple type, approximately half-round in section, and positively controlled by means of a hydraulic ram, which causes the bucket to pivot along the outside edge. Some machines, however, employ a hydraulic grab which is operated by a " clam-shell " action.

More expensive ditchers are operated by a more powerful external hydraulic system, with an independent oil supply. The machine may employ 6-7 hydraulic rams, and is usually of the " back-acter " type. In some machines the boom pivot may be offset so that the bucket is drawn along the line of the ditch. In this type, a tapered bucket which automatically batters the ditch bottom to a suitable shape may be used.

There are many other types of ditchers - e.g., a high-speed rotary machine, which is driven by a hydraulic motor. Most of the more complex machines are, however, more suitable for use by contractors than by individual farmers.

Chapter VII

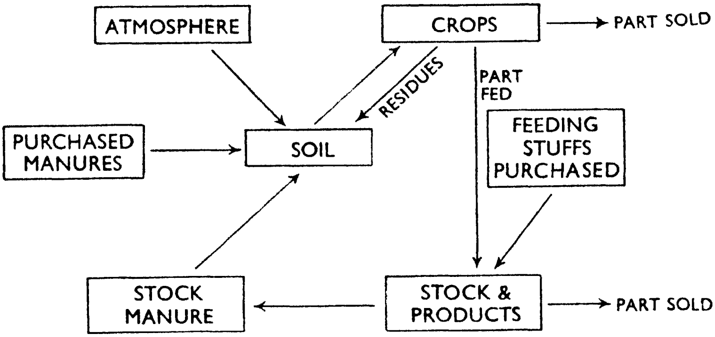
MANURES AND MANURING

In the section dealing with soils the meaning of the term fertility, as well as the various properties of natural soils and the constituents which contribute to it, were considered. It is the purpose of this section to consider what effect the growing of crops and husbandry generally can have upon fertility, what practices may lower it, and particularly by what agencies it can be maintained or augmented.

The Fertility Balance. Fertility of the soil has been shown to depend partly on the physical conditions or tilth, partly on moisture conditions, partly on bacterial activity, and partly on chemical composition. Man attempts to influence these various factors by suitable tillage operations, by rotations of crops, and by the addition of a number of manurial substances which will be considered in detail. Some of these are added for direct nutritional reasons while others fulfil a dual purpose of feeding the plant and improving or maintaining physical condition, thus increasing moisture retention and making the soil a more suitable medium for crop growth.

Leaving aside for the moment the question of tilth, it is a useful starting-point to consider manuring from the standpoint of plant nutrients and to view the soil of the farm as a unit containing a limited amount of organic matter, nitrogen, phosphoric acid, potash, lime and also a number of other substances required in greater or lesser quantities—the trace elements. Of the trace elements the soil usually contains all that successive crops require except under certain exceptional circumstances already referred to in a previous chapter (see p. 22). Before the farm is established, vegetation of sorts occupies the land. This vegetation is supplied with nutrients from the soil and from the atmosphere, and when it dies upon the ground it adds to the stock of humus and nitrogen, and returns the mineral matter which has been drawn from the soil. By this process the soil has gradually arrived at a certain level of fertility. If now man takes possession and grows crops to sell away, he at once disturbs the balance of this system, and very rapidly lowers the fertility level of the soil by removing soil constituents in the crops and also by causing other constituents to be lost in drainage. This loss may not be appreciable when considered in relation to the *total* reserves present in any soil, but it must be remembered that the loss falls primarily on the *available* portion of the total reserves, and so the soil becomes unable to provide anything like the amounts of some of the individual constituents necessary to keep up a high level of production. If the crops are used solely for feeding the farm stock or for the production of animal products sold off, the inroads on fertility are less severe than when the crops themselves leave the farm since some part of the nutrient constituents are retained and returned eventually to the soil in the animal's excreta. Nevertheless, even under the best-managed conditions of mixed farming, some losses of soil constituents are bound to occur. A compensating effect is brought about when food, especially of the more concentrated kind, is bought in for the stock, because a good portion of its nitrogen, phosphates and potash remains on the farm, thus augmenting the natural reserves. Finally, the balance of fertility is greatly affected by the deliberate importation of fertilising substances from extraneous sources.

The main lines of movement of nutrient materials are shown in the following diagram :



From this it will be seen that a certain amount of nutrient material is constantly being removed from the farm in the form of crops or animal produce ; a certain amount is circulating—from the soil, through the crops, stock and farmyard manure, back to the soil ; and a certain amount is added from the atmosphere (i.e. nitrogen and carbon), and from purchased feeding-stuffs and manures. Thus it will be realised that it is possible to balance gains and losses by adjusting the farming system to the inherent fertility of the soil, or to raise the level of fertility by additions of fertilising materials and so increase its production or turnover. It is equally possible, also, by specialising in one direction, to impoverish the soil in one or two of the main constituents unless measures are taken to replenish them from outside sources.

Many different systems of farming are practised or can be designed to make the most of the fertility of the soil ; but the decisive factors in adopting any one system are mainly economic, so that it is more useful to consider various prominent farming operations and the fertilisers procurable than to discuss the subject from the point of view of any particular system of farming. Any farming project must have a plan behind it. The maintenance of fertility will need to be thought out in relation to all parts of that plan. In this way it will be possible gradually to increase the soil's store of nutrients or, in certain special circumstances, to depress it. Nowadays there is a tendency towards supplying only those amounts of mineral fertilisers thought to be necessary for the particular crop to be grown. This opinion is based partly on experience of the use of nitrogenous fertilisers, where any excess beyond the present crops' needs may not be available to the succeeding crop, and partly on the somewhat spectacular results obtained by the placement with a combine drill of very small quantities of fertiliser close to the seed.

Fallowing. The benefits of fallowing as a means of restoring the fertility of the soil were forced on the attention of the farming community at an early date. When agriculture consisted mostly of corn growing and sparse grazing, man soon found that he inevitably exhausted the soil to a marked extent : he was forced to adopt a system whereby the land was left uncropped for a period of months or even years. He next discovered that it was helpful, not simply to leave the soil to its own efforts at recuperation, but to assist the process by tillage during the resting period. Thus the systematic fallowing of land became an established practice and in some systems of farming, particularly on clay soils, remains so to this day. The explanation of the benefits produced is not even now fully understood, but it is known to a certain extent. Some of the more obvious beneficial effects of the fallow have already been referred to in the chapter on tillage, such as the killing of all kinds of weeds by the actual drying out of the soil, the improvement of soil structure by alternate drying and wetting, the effects due to temperature changes, and the accumulation of nitrates through the work of nitrifying bacteria in the absence of a growing crop. There are, however, other benefits beyond these. It may be that the drying or heating effects on the colloidal coverings of the soil particles are such that, on re-wetting, a larger amount of the phosphate and potash in the soil comes into solution, or at all events is rendered more suitable for absorption by the plant roots.

Green Manuring. Occasions arise in farming practice when it is preferable, instead of leaving ground unoccupied for an interval, to grow a crop with the express purpose of ploughing it in later. This process, known as green manuring, is a means of adding humus to a soil and has undoubted advantages in some circumstances. If it is desired to follow a main crop with a green manure crop in the same year, it is essential to get the latter in quickly before the bare compacted surface left by its predecessor becomes totally dried out, a condition which follows rapidly, in dry weather, on the removal of the covering crop. Green manuring is also useful as a means of conserving the nitrates accumulated in the soil during a fallow period, if a rotation crop is not planted before winter. The winter rains would wash out the nitrates from an uncropped soil, but a green manure crop planted after a fallow absorbs the nitrates and holds them in its own tissues until it is ploughed under. Various crops are employed, such as mustard on chalk soils, lupins on light sandy soils, tares on heavy soils and Italian ryegrass on a variety of soils. The process is not always successful for, unlike an application of farmyard manure, it does not seem able simultaneously to raise the organic matter content and at the same time to increase the supply of available nitrogen. If the green material is old and fibrous it increases the soil's store of humus but adds little available nitrogen. On the other hand if the green crop is young and succulent it may increase the amonnt of available nitrogen but add little to the soil's store of organic matter. Apparently this latter effect is due to enhanced activity of the soil organisms, causing them not only to attack the easily decomposable succulent green material but also the stores of more stable organic matter. The factors which make green manuring successful are much the same as those which operate in ley farming or alternate husbandry, and no doubt are partly physical, partly biological as well as partly chemical. The land, when under a three or four years' ley, is considerably enriched in humus and nitrogen, whilst at the same time producing both pasturage and crops of hay. When the ley is broken up, and ploughed under, beneficial results become apparent both in the ease with which a tilth is established and in the enhanced yields of the arable crops which follow. Increased results can often be obtained by judicious treatment of the green crop with fertilisers, which not only increase the bulk of the organic material available for ploughing in but also build up the elements, nitrogen, phosphate and potash into more complex compounds later to be used as slow acting reserves.

FARMYARD MANURE

In spite of the growth of the fertiliser industry, farmyard manure is still one of the mainstays of British crop production and is worth all the care and attention which can be bestowed upon it. It is the product of the intermingling of the fæces and urine of various farm animals with straw or some other form of litter. There is obviously great variation in its composition, but in spite of this the properties of the final product are strikingly constant. A consideration of some of the factors involved in the making of dung is of use in explaining the points of practical management of this commodity.

The chief fertilising value of the material fed to animals obviously lies in its content of nitrogen, phosphoric acid and potash. Table 2 shows the approximate percentage of these elements in different fodders :

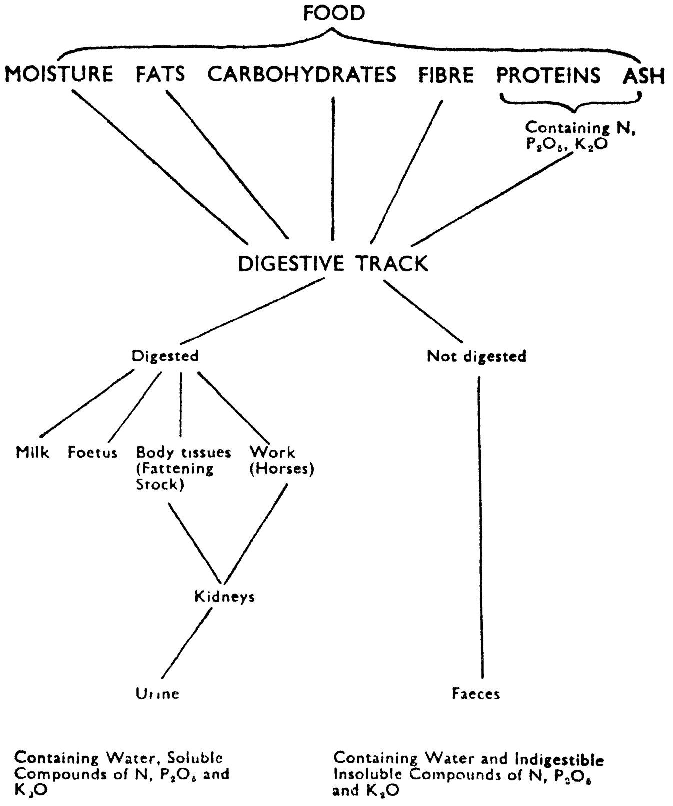
TABLE 2

FERTILISING ELEMENTS IN FODDERS (PER CENT.)

Fodder.	Nitrogen (N).	Phosphoric Acid (P_2O_5).	Potash (K_2O).
Decorticated cotton cake . . .	6·7	2·8	1·8
Undecorticated cotton cake . .	3·6	2·5	1·6
Beans	4·0	1·2	1·3
Oats	1·6	1·3	0·7
Meadow hay	1·5	0·6	2·0
Oat straw	0·5	0·3	1·5
Swedes	0·2	0·09	0·3

Working animals, fattening adult stock and store animals retain little of the constituents of their food : grazing stock, pregnant animals and animals in milk retain a good deal, especially the nitrogen and phosphoric acid. It should be observed that while most of the potash excreted occurs in solution in the urine, much of the phosphoric acid appears undigested in the faeces.

Different foodstuffs are of varying digestibility; some of their constituents pass through the animal unchanged, and it seems reasonable to assume that what proves indigestible to the animal is not likely to be available to the plant until it has been broken down by some suitable agency. Of the portion of the food digested, some is used to provide energy for the animal and is in effect burnt up, some is stored as fat, and some is used to replace body tissues. The undigested portions are voided as fæces. The proteins are the nitrogen-bearing constituents, and much of the proteins may be used in producing growth (flesh), milk or young, thus ultimately leaving the farm. But a certain amount of the protein is used to replace similar compounds consumed by wear and tear in the animal's body, and this is the portion whose nitrogen appears in the urine as comparatively simple compounds, such as urea, which have been collected in a soluble form by the kidneys and thence passed out dissolved in water. Of the ash constituents, a little of the phosphoric acid and most of the potash also appear in the urine. The main trends of these various processes are set out graphically below.


FOOD
MOISTURE
FATS
CARBOHYDRATES
FIBRE
PROTEINS
ASH
Containing N, P_2O_5, K_2O
DIGESTIVE TRACK
Digested
Not digested
Milk
Foetus
Body tissues (Fattening Stock)
Work (Horses)
Kidneys
Urine
Faeces
Containing Water, Soluble Compounds of N, P_2O_5 and K_2O
Containing Water and Indigestible Insoluble Compounds of N, P_2O_5 and K_2O

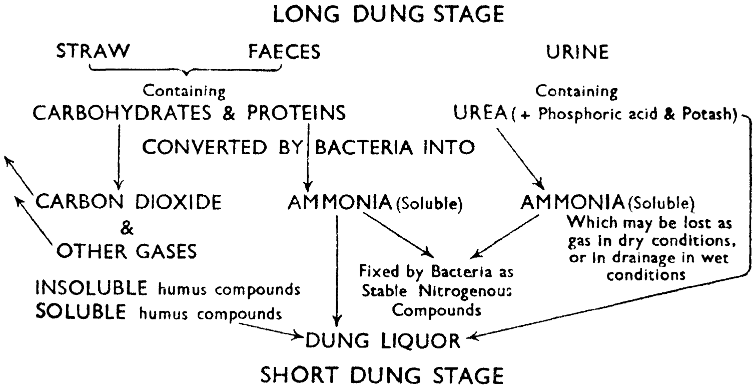
The litter also has a definite content of manurial constituents, as is shown by the analysis of oat straw in the table on page 166. The first function of litter is to absorb the urine, although conditions in which it accomplishes this to any considerable extent are rare. Straw will absorb two or three times its own weight of water, while peat moss can assimilate as much as ten times its own weight of water and in addition can absorb considerable amounts of ammonia gas, a compound which is formed in considerable quantities during the decomposition of urine. Its advantage over straw in absorptive powers, however, is offset by its stability and its resistance to decay, so that it does not rot down in the same desirable manner as farmyard manure made from straw litter.

Chemical Changes occurring in Dung. At the time of production, farmyard manure consists of a crude mixture of straw, fæces and urine, commonly termed " long dung " ; but this at once begins to undergo various changes which result in it ultimately producing a very uniform material in which many of the original differences of composition, due to the type of animal, richness of food, amount and type of litter, have been considerably mitigated if not obliterated. To begin with, the bulk of the soluble manurial constituents are in the urine, so that to the extent that this is allowed to drain away, they become a total loss. Liquid manure tanks and suitable drainage systems avoid this loss but, with the increased use of water for washing purposes in cowsheds, the difficulty of using them to the best advantage has been aggravated. The soluble compound of nitrogen, urea, is very quickly converted by bacteria into ammonia. Its presence, particularly in stables, is usually obvious. Ammonia appears as a gas whenever the litter or the floor dries out, but so long as conditions are moist it remains in solution. This change of urea into ammonium compounds is only one of many which are brought about by bacteria in the manure heap. Each change comes into prominence as the conditions of moisture and aeration in the heap become suitable.

The most important chemical changes which take place in the manure heap are as follows :

1. The conversion of urea into ammonium compounds.
2. The fermentation of the carbohydrates of the litter and fæces with the production of heat, various gases (such as carbon dioxide, methane and hydrogen) and a decayed mass of organic matter richer in nitrogen and darker in colour than the original straw.
3. The breaking down of the proteins of the litter and fæces into simpler compounds of nitrogen such as ammonia.
4. The assimilation and fixing of nitrogen as protein in the bacteria.

These changes become manifest in the gradual disappearance of any recognisable structure, the whole heap tending to become uniform in texture and colour. The raw, soluble compounds of nitrogen gradually disappear, and drainage from the heap takes on a dark brown or black colour. This is " dung liquor ", and its appearance is due to the presence of soluble compounds of ammonia and organic matter. When all these changes are well advanced, the heap is in the condition known as " short dung ". There is inevitably a great amount of wasting in the heap, both as regards total weight and amount of fertilising constituents. Observations indicate that some 15 per cent of the nitrogen is lost in the first few days, and that this loss steadily increases to as much as 40 or 50 per cent as storage continues. Yet, in spite of this, the final product as a rule is richer in nitrogen than the original components owing to the comparatively greater loss which falls on the non-nitrogenous constituents. In the diagram below the main changes which take place in a manure heap are set out:


LONG DUNG STAGE
STRAW
FAECES
URINE
Containing
CARBOHYDRATES & PROTEINS
Containing
UREA (+ Phosphoric acid & Potash)
CONVERTED BY BACTERIA INTO
CARBON DIOXIDE
&
OTHER GASES
AMMONIA (Soluble)
AMMONIA (Soluble)
Which may be lost as gas in dry conditions, or in drainage in wet conditions
Fixed by Bacteria as Stable Nitrogenous Compounds
INSOLUBLE humus compounds
SOLUBLE humus compounds
DUNG LIQUOR
SHORT DUNG STAGE

The initial losses of nitrogen may be minimised by allowing manure to accumulate beneath the animals, a practice carried out with success in the case of fattening animals in suitable feeding-boxes. The daily removal of manure leads to the heaviest initial losses, especially if it is thrown out into a yard in casual fashion. Losses in yards and heaps may be cut down by collecting the manure in a well-compacted heap on a concave surface kept free from surface and roof drainage. The utmost saving in constituent nutrients is obtained by immediate removal to the field and ploughing into the land in fresh, long condition.

The Composition and Use of Dung. Enough has been said to describe the nature of the fertilising constituents in farmyard manure, both in the " long " and in the " short " dung stage. An average sample contains about 0·5 per cent nitrogen, 0·25 per cent phosphoric acid and 0·5 per cent potash, so that the amount of phosphoric acid is low in comparison with the other constituents. If these figures are converted into their equivalents of common nutrients, 10 tons of farmyard manure will contain 1 cwt. nitrogen, ½ cwt. phosphoric acid and 1 cwt. potash. The presence of these nutrients does not mean, however, that they are in an easily available condition. An average figure for their availability has been deduced from an examination of the results of many experiments in which the effect of dressings on yield were being examined. Most of the nitrogen in dung is contained in organic forms and some only becomes available for crops. Likewise, the phosphates and potash are less available than those in fertilisers.

By comparing field experiments conducted both with and without farmyard manure, it was found that on dunged land fertiliser dressings can be reduced by 0·3 cwt. of N (equivalent to 1·5 cwt. sulphate of ammonia), by 0·4 cwt. P_2O_5 (equivalent to 1¼ cwt. of superphosphate), and 0·6 cwt. K_2O (equivalent to 1¼ cwt. muriate of potash) per acre to allow for the amounts of these nutrients in 10 tons of farmyard manure.

Farmyard manure, however, does not owe its value solely to the nitrogen, phosphoric acid and potash it contains : indeed, its beneficial effects are probably due in a greater degree to other factors. There are five points with regard to the humified organic matter in it which must be borne in mind. Firstly, this constituent exerts a profound influence on the tilth of the soil, whether it be light or heavy. It opens up heavy soils and gives body to light soils. It opens up heavy soils by a mechanical loosening effect, it increases pore space and stabilises the soil crumbs, improves drainage and ventilation thus favouring the activity of micro organisms. Light soils cohere through the presence of colloidal humus matter, the pore space and permeability are reduced and water-retaining power increased. The increase in water retention is illustrated by the data coming from Rothamsted experiments. A plot treated every year with farmyard manure showed 3–4 per cent higher water content during the experimental period than the neighbouring plot to which no farmyard manure had been applied. From the same station comes further information that the water-stable crumbs in the soil of more than 0·5 mm. diameter were increased from 28 to 50 per cent following an annual application of farmyard manure over many years. Secondly, its content of nutrient compounds makes an almost permanent addition to the fertility of the soil which, by its continuous use, is considerably increased. Thirdly, it exerts a peculiar but markedly beneficial effect on young leys of leguminous crops such as clovers. Fourthly, either by reason of its own composition or by some action on the soil as yet not understood, it makes available trace elements to overcome conditions of deficiency affecting the growing crop. Finally, considered as a whole, the use of farmyard manure is probably the best means of maintaining fertility, for it mitigates to a great extent the effects of seasonal variations in weather, and in any one year it gives the most equable effect.

In the making of farmyard manure the great importance of the urine lies in the fact that its soluble nitrogen compounds enable the straw-rotting organisms to do their work, a point which has a bearing on the quantities in which straw should be supplied as litter. To prescribe a definite figure, such as 1 ton of straw to every 100 lb. of digestible protein in the food supplied, may be a counsel of perfection, but it is based on facts which are well worth attention in the making and management of farmyard manure.

Compost. Some years ago work at Rothamsted resulted in the elaboration of a process for the production of compost from straw and other vegetable refuse. This followed on discoveries made on the nature of the changes proceeding in the manure heap. Briefly, it was found that two sets of organisms, working independently, brought about two main results, the one the rotting of the straw and the other the fixation of nitrogen. It was also found that the former needed a supply of readily available nitrogen compounds to enable it to go on. By building up a heap of straw, layer by layer, each of which was well watered and given a sprinkling of chalk, and by washing in some easily soluble nitrogenous fertiliser such as sulphate of ammonia, a complete rotting down of the heap to a product which was very like short dung, and which gave similar results in the field, was effected. This material has been variously called artificial farmyard manure or compost.

During the Second World War much experimental work was done on methods of making compost from straw and in the measurement of crop yields resulting from their use. Quantities ranging from small heaps to large ones containing some hundreds of tons of straw were made but the process of composting demands a considerable amount of labour and a plentiful supply of water. Large quantities of straw compost can be made only if corn growing is an important part of the farming economy. Successful experiments in composting straw with sewage sludge were carried out in several counties but these have been largely discontinued. It has been shown that the whole output of sludge from a sewage works serving 3,000 persons requires about 1 ton of straw weekly. The use of the combine harvester has resulted in much straw being ploughed directly into the land after harvest. This is usually carried out after the addition of 1 cwt. per acre of a soluble nitrogenous fertiliser and may be looked upon as still another method of composting but with the difference that the decomposition processes go on in the soil rather than in the heap.

On farms where there are few or no cattle the replacement of dung by other forms of humus is an important problem. The use of artificial farmyard manure or straw compost is virtually undeveloped. Green manuring, or ploughing-in of straw, or a combination of both practices may be a solution.

Liquid Manure. Reference has been made to the urine of farm animals, to its composition, and to the loss involved in the absence of any liquid manure tank system. The profitable utilisation of liquid manure, however, bristles with difficulties. The volume produced may be too large to store or even to handle, and whereas a tank needs to be emptied at regular intervals, the land is not always ready to receive its contents. It is most easily dealt with, therefore, on grass land, on which it can be applied at most times. It is impossible to give a composition analysis for it owing to the enormous variations of dilution to which it is subject. Undiluted urine drainings may be so concentrated as to be harmful to vegetation, while yard drainage during spells of wet weather may be little more than polluted water. A common strength, however, is one at which 1,000 gallons of liquid manure contain the equivalent of 1 cwt. sulphate of ammonia, $\frac{1}{20}$ cwt. of superphosphate and $\frac{4}{5}$ cwt. of muriate of potash. Liquid manure is in effect a nitrogenous stimulant and encourages coarse rank growth. Accordingly, its best use is on grass land when yield rather than quality may be desirable.

Sewage Sludge. Large quantities of sewage sludge are produced in all the large towns. Urban sewage consists of about 1 part of solid matter in 2,500 parts of liquid, and the bulk of the solid is separated by sedimentation and partially dried in lagoons freely exposed to air. Practically all the water soluble salts in the original sewage pass into the effluent, and much nitrogen, phosphate and potash are thus lost. Most of the sewage sludges undergo aeration during their production and in some cases are later allowed to heat in heaps. At a moisture content of less than 55 per cent a sludge will crumble and can be easily handled. Sewage sludge does not have the same beneficial effect on soil texture as does farmyard manure.

The percentage composition of raw sludge, digested sludge and farmyard manure is set out in Table 3 :

TABLE 3

COMPARATIVE PERCENTAGE COMPOSITION OF SEWAGE SLUDGES AND FARMYARD MANURE

	Dry Matter.	Organic Matter.	Ash.	Total Nitrogen.	Inorganic Nitrogen.	P_2O_5.
Raw sludge	40	20	20	0·9	0·05	0·5
Digested sludge . . .	52	23	29	1·4	0·06	1·1
Farmyard manure . .	20	16	10	0·6	0·06	0·4

Contrary to older opinion, digested sludges (those in which an aerobic fermentation has taken place) are more active than raw ones. The process of digestion improves the physical condition and also increases the proportion of available nitrogen.

Heavy dressings of sewage sludge furnish large amounts of phosphoric acid, half of which may be regarded as being as effective as the phosphoric acid in superphosphate. By comparison with farmyard manure, sewage sludges are poor in potash, a fact which is borne out by field experiments. Materials present in certain industrial sludges (zinc, etc.) may be directly injurious to crops.

Much field experimental work has been carried out using sewage sludges in order to obtain an opinion on their value and use. Usually sewage sludge is compared with dung, and the results of 26 trials on potatoes in 1942 and 1943 show the following figures :

No organic matter	7·5 tons of potatoes per acre
Sludge (15 tons per acre fresh material)	8·5 ,, ,, ,, ,, ,,
Dung (12 tons per acre fresh material)	9·5 ,, ,, ,, ,, ,,

In all these trials adequate potassic fertiliser had been applied to the land. Yet even when the potash deficiency was made good, the immediate effect from sludge was much less than from an equal weight of average farmyard manure. Little benefit could therefore be expected from dressings of only a few tons of sewage sludge per acre.

In twelve experiments carried out in 1943, the results showed that where no sulphate of ammonia was used the yields of potatoes from sludge approached those from dung, but where sulphate of ammonia was used, dung was far superior to sludge. Part of this effect is believed to be due to the superior effect of dung in improving the soil structure. On crops which occupy the land for longer periods than potatoes, sewage sludge gives better results. In the few experiments where it has been possible to measure results, the residual effect of sludge proved to be as great as that of farmyard manure. Some municipal authorities compost sewage sludge with other forms of town refuse such as dust-bin siftings. The resultant material is of the nature of compost but contains a high ash content. From the point of view of the authorities the production of such material partly solves the difficulty of disposal of voluminous and often unwanted materials by providing a substance which can readily be incorporated with the soil for crop and vegetable production.

Poultry Manure. It is estimated that 1,000 birds, normally housed, will produce 2 cwt. of droppings in a day. The analysis of these droppings varies between 1 and 4 per cent nitrogen, 1 and 3 per cent phosphoric acid and 0·5 and 1·5 per cent of potash, so that 20 cwt. of it should constitute an effective dressing per acre. The value of the fertiliser is partly retained if it is stored under a roof in airy conditions, and mixed with one-third to one-half of its own weight of dry earth as it accumulates. This improves the physical condition of the manure and lessens the loss of nitrogen as ammonia. Almost all of the fertiliser ingredients will be conserved if the poultry are kept on deep litter, but will be diluted by the absorbent material. Processes have been elaborated for conserving, drying and grinding poultry manure.

Seaweed. Seaweed has long been used in coastal districts for bulk application to the soil. It contains about 80 per cent moisture, has more potash than farmyard manure and has the following approximate percentage nutrient content in the fresh condition: 0·6 nitrogen (N), 0·2 phosphoric acid (P_2O_5), 2·0 potash (K_2O).

FERTILISERS

In ordinary farming the purchase of fertilisers consists of buying commodities containing one or more of the principal plant nutrients, namely, nitrogen and phosphoric acid and potash. Each of these substances has its particular effects on plant growth, and as the form in which it is offered to the plant may also have specific effects, it will be profitable to consider individually the materials which are obtainable. Of these there is a wide choice available, and for each one there can be claimed special advantages in certain circumstances, so that a knowledge of the properties of the various kinds may enable the farmer to come to a decision as to which is most likely to serve him best for any particular purpose. It is useful, also, to bear in mind that some kinds are available only in comparatively limited quantities, a fact, among others, which has its effect on the price at which they can be bought. In the majority of cases a grower will use fertilisers to obtain a reasonably rapid effect, but in some cases he may be content to get a slower effect while gradually building up the fertility of his soil. In the former case he is best served by a material which is in a form immediately assimilable by the plant, or readily and quickly converted by bacterial or other action to an available form. Generally speaking, the more soluble it is in water the quicker it will act. In the latter case, substances of a more durable nature are desirable, such as will release the desired constituent slowly but evenly over a long period, so that regular additions continually increase the reserve in the soil, and hence the supply at any particular moment. Other points which are of practical importance are the keeping qualities of the manure, its concentration, the ease and comfort with which it can be handled, and the evenness with which it can be spread

NITROGENOUS FERTILISERS

The effects of nitrogen-containing manures upon plant growth are amongst the most spectacular which can be achieved by manuring, for nitrogen is the food material which is especially responsible for growth, particularly of foliage and stems. Rapid growth of these organs is to be desired on occasion, as in kale, but it may become a handicap if, for instance, the production of grain is the main object of the crop. The excessive use of nitrogenous fertilisers encourages the growth of the normally less valuable parts of some crops and may influence the proportion of straw in a grain crop, or of leafage in a root crop. Late season applications (mid May-mid June) of nitrogen fertilisers to cereals tend to increase the yield of corn rather than straw. The use of nitrogen has a marked effect on the appearance of herbage, giving to it a luscious green appearance ; indeed, the lack of nitrogen is often shown by a stunted growth, and also by pale or yellowish-green leaves. There are two things to beware of in the use of a quick-acting nitrogenous manure—its tendency to retard the ripening processes and its tendency to produce succulent and flabby growth. These effects become apparent more quickly when the soil is deficient in phosphates and potash. Flabby growth due to this cause has two drawbacks ; it may be unable to support the weight of its own structure and so become laid, or it may more readily fall victim to the attacks of fungoid diseases.

Organic Refuse Materials. The important organic refuse manures and the percentage nitrogen they contain are as follows :

	Percentage Nitrogen.		Percentage Nitrogen.
Animal Residues—		*Animal Residues (continued)—*	
Shoddy	3-15	Fish manure	6-8
Hoof and horn . . .	13-14		
Dried blood	13	*Vegetable Residues—*	
Leather refuse . . .	12	Castor seed meal Rape ,, ,, . .	5-8
Fur, hair, skins, feathers.	8-12		
Meat meal	10	Malt culms or dust . .	3-4

Of those mentioned in the list above certain fertilisers, viz. meat meal, fish manure, oil seed refuse, etc., contain phosphoric acid and potash in addition to the nitrogen.

The Animal Residues originally contain large quantities of protein, and unless they become contaminated with dirt or are mixed with other substances during the manufacturing processes, they may contain up to 15 per cent nitrogen. Their utility and value depend partly on their nitrogen content but more on their physical state. For instance, the barbs of a feather or finely ground fragments of hoof and horn have an obvious advantage over pieces of shoe leather when considered as fertilisers. All these materials may be regarded as comparatively slow-acting manures, useful for raising the fertility of the soil, i.e. they have residual values. They are therefore in demand by intensive growers for use in market gardening, hop and fruit growing. This, coupled with the rather limited supply, probably explains the fact that they are usually the most highly-priced forms of nitrogen.

Shoddy is a by-product of the woollen industry. Pure wool is wholly protein and contains 15 per cent nitrogen, so that the fragments which are discarded in woollen manufacturing as shoddy will approach that figure. But in some processes the fabric manufactured contains an admixture of cotton, a substance which contains no nitrogen, so that it is possible to have almost any percentage of nitrogen in shoddy according to the nature of the material being made up. For this reason shoddy receives special mention in the Fertilisers and Feeding Stuffs Act, which exempts it from the statutory declaration of its nitrogen content. Shoddy is, on the whole, a finely divided material, but it is of such a nature that it is bulky and not easy to spread in small quantities. It is highly esteemed by intensive growers, who often apply it at the rate of a ton per acre.

Hoof and Horn also contains a high proportion of protein and consequently of nitrogen. It is dried and ground so that an effective spread can be obtained with a few hundredweights to the acre.

Dried Blood also is marketed in a very good physical condition. Its content of nitrogen varies as sometimes the drying process is helped by the addition of lime which, of course, has its own value but must inevitably reduce the percentage of nitrogen in the final product. This material is classed as a moderately quick-acting fertiliser.

Leather refuse is occasionally available as a fertiliser, as are also fur, hair, skin, feathers and meat meal, etc. All these commodities vary so much from one consignment to another that it is impossible to describe them precisely. They all have potential fertilising value, but their value can only be computed with difficulty. Sometimes the material is of such a tough nature that it can be recognised in the soil for years ; in this case it is obviously of poor value as a manure. It is necessary that it should be finely divided or that it should be chemically treated in order that it may easily undergo the changes by means of which its nitrogen content becomes available for plants.

The Vegetable Residues form a group by themselves. They are usually the result of processes which have extracted certain constituents of seeds for technical purposes, leaving a residue which for some reason or other is unsuitable for use as a foodstuff. It will thus be realised that these residues cannot as a rule be very rich in nitrogen. The average seed contains carbohydrates, fibre, ash, moisture, oil and protein. In the case of rape and castor seed the last two are the most abundant constituents. The oil is extracted for various purposes, leaving a residue in which the protein provides nitrogen to the extent of about 6 per cent of the bulk. Small amounts of phosphoric acid and potash are also present.

All these organic manures owe their chief value to their nitrogen content, this often being of a form which becomes available gradually. In some instances the conversion is so rapid that an immediate response can be seen in the crop, and the manure is practically used up in one season: this happens with dried blood and seed refuses. With others, such as shoddy, hoof and horn, fur, leather, etc., there are greater or less residual effects, so that their use results in a semi-permanent improvement in the fertility of the soil. This property is reflected in the practice of awarding compensation for their use on the termination of a tenancy.

Inorganic Nitrogenous Fertilisers. The fertilising value of many of the organic refuses has been known for years, but during and since the last century a number of simple chemical compounds have been discovered and developed as cheap and convenient forms of nitrogen. Of these, sulphate of ammonia, a by-product from gasworks, and the naturally occurring nitrate of soda of Chile were for many years the chief representatives, but at the present day they are equalled in importance by the many synthetic forms of nitrogen now manufactured, particularly sulphate of ammonia, nitrate of ammonia, nitrate of lime and calcium cyanamide. The discovery of means by which the huge reserves of gaseous nitrogen in the atmosphere could be utilised to produce solid nitrogenous compounds was made before 1914, and the first World War gave a tremendous impetus to commercial production, so much so that the older by-product and natural forms have now fallen to second place in importance.

The merit of these fertilisers lies in the fact that they provide nitrogen in a concentrated form, convenient to handle, comparatively cheap, and readily assimilable by plant roots. Nitrates are the compounds which in the soil form most of the plant's immediate source of nitrogen, and ammonium compounds are only one stage removed in this respect, being easily converted to nitrates by the action of certain bacteria in the soil. Each kind has its merits and demerits, and to make the best choice it is necessary to consider these in connection with the soil and crop on which it is intended to use them. For instance, ammonium compounds are better suited to well-limed soils, while fertilisers containing a lime base may have an advantage for general purposes on soils which are, or tend to be, acid. Ammonium compounds are generally regarded as more suitable for potatoes, while nitrates have an advantage with such crops as wheat or mangels. It is well to remember, however, that these differences are more relative than absolute, as ammonium compounds soon undergo nitrification when conditions are favourable and are converted into nitrates. In fact, it may well be that the ammonium ion is itself absorbed by some crops and utilised therefore as a source of nitrogen. The main characteristics of our chief nitrogenous fertilisers will now be described.

Sulphate of Ammonia. Whether produced in gasworks or synthetically, sulphate of ammonia always has the same properties. It is one of the most useful individual fertilisers, and is composed of small, needle-like crystals which are perfectly dry when fresh and which distribute well and evenly. Nowadays sulphate of ammonia is free from traces of acid, with the result that it can be kept for a reasonable time without losing condition. As it does not contain a metallic base, its conversion in the soil to nitrate entails the loss of a certain amount of the reserve lime, which combines with the sulphate radicle and is washed out of the soil. The effect of this action soon becomes apparent on soils which contain very little free lime, and continued use will in time decrease the *p*H of light soils poor in lime. About 1 cwt. of calcium carbonate is removed by each hundredweight of sulphate of ammonia applied. Its properties make it the most widely used nitrogenous constituent in fertiliser prescriptions. It has a nitrogen content of 20·8 per cent.

Nitrate of Soda. This substance is probably the most quickly effective of all forms of nitrogen. It does not contain so much nitrogen as its old rival sulphate of ammonia, but no longer falls behind it in respect of physical condition. The crystals are larger, more irregular and more inclined to cake, but on all these points it has of late years been improved. Nowadays a granulated form containing 16 per cent nitrogen is produced in addition to the crystalline (16 per cent) form. It is hygroscopic in tendency and so does not keep its physical condition so well. To a limited extent the sodium can replace potash as a plant nutrient : this characteristic gives it a special value with potash-loving crops such as the mangel and sugar beet. Another, but less desirable effect, connected with the same action is that its continued use on heavy soils, or its liberal use in intensive farming on most soils other than the lightest, leads to the production of sodium clay, whose presence becomes evident in poaching, deflocculation, stickiness or loss of tilth.

"Nitro-Chalk." This material is a blend of by-product chalk and synthetic nitrate of ammonia. It is produced in even granules, supplying both nitrate and ammoniacal nitrogen and it suits all soils. For many years it was made only with a content of 15·5 per cent nitrogen, but in recent years a more concentrated form containing 21 per cent nitrogen has appeared.

"Nitra-Shell" is another manufacturer's product of a similar character and is available in two grades containing 20·5 per cent and 23 per cent nitrogen respectively.

Calcium Cyanamide. Calcium cyanamide, of which one brand was formerly called " Nitrolim ", is a synthetic nitrogenous fertiliser which was popular with a restricted number of farmers until the outbreak of the 1939–45 war. Its main features are a slower but more prolonged action, and the possession of a certain amount of free lime, incident to its commercial production. In practice it is sometimes found disagreeable to handle, and—although improved by oiling and granulating in recent years—it is advisable to distribute and work it into the land ten days or more before seeding to avoid the possibility of damaging germinating seeds or young crops. This property of damaging certain types of foliage is sometimes made use of in weed control. Its greatest value is as a nitrogenous manure on soils short of lime, and its use has been recommended as the source of nitrogen in compost production.

Nitrate of Lime. Nitrate of lime, or calcium nitrate, is manufactured from atmospheric nitrogen which has been fixed by synthetic processes. It contains no free lime, contrary to the impression often created by its name, but as it contains the calcium base it makes no inroads on the lime reserve of the soil and provides another useful fertiliser for acid soils and those which have only a small lime reserve. It is markedly hygroscopic and quickly becomes liquid on exposure to air, a fact well realised by anyone who has handled it. This characteristic causes it to enter the soil fairly quickly even in dry weather. It has the disadvantage, however, that it is necessary to pack it in airtight containers, and once these are opened the contents must be used immediately as the fertiliser rapidly loses its condition. It is not readily obtainable in this country. The nitrogen content is 13 per cent.

Anhydrous Ammonia. Anhydrous ammonia containing about 80 per cent nitrogen is used extensively in some countries and particularly in the U.S.A. It consists of gaseous NH_3 and is transported under high pressure in cylinders. It has been tried out experimentally in this country and found to equal sulphate of ammonia as a fertiliser. It has to be applied a few inches below the surface in a gaseous form and is then held by the soil. None, so far, is being used commercially in this country.

Aqueous Ammonia. Ammonia in aqueous solution is being used quite extensively in the form of crude *gas liquor.* This is generally carried in bulk and applied directly to the ground—mostly grassland—by contracting firms. It has a good fertilising value, albeit scorching the grass somewhat, especially if applied in the growing season. The precise cause of scorch is not fully understood, but is probably due in part to the ammonia itself and partly to the impurities in the liquor. Recent experiments carried out both on grass and arable crops suggest that it has about $\frac{3}{4}$ the fertilising value of sulphate of ammonia compared on the basis of equal applications of nitrogen. It contains 1–4 per cent nitrogen.

Other Synthetic Compounds. There are several other new synthetic nitrogenous compounds suitable for use as fertilisers. Although they are not as yet freely on the market, all of them have been experimentally tried out, so that their characteristics are fairly well known. Some may appear in due course as common commodities, or they may be developed in connection with the new compound and concentrated mixed fertilisers which are now beginning to challenge the older and more familiar special purpose compounded manures. Among such are nitrate of ammonia, containing 35 per cent of nitrogen ; and urea, containing 47 per cent of nitrogen. In the main they can be regarded as being similar to sulphate of ammonia, except in the matter of concentration.

Soot. Soot is widely used, but not in very considerable quantities, as a nitrogenous fertiliser. It contains its nutrient material in the form of sulphate of ammonia. The best material comes from domestic chimneys ; boiler soot is of limited value. Its continued use in old gardens probably accounts, at any rate in part, for the dark colour of the soil. It is said to have a beneficial effect on the structure of clays.

PHOSPHATIC FERTILISERS

Equal in importance among the plant nutrients commonly added to the soil by means of fertilisers comes phosphoric acid. This has its own peculiar effects on the growing plant. It fosters the development of the seedling and enables it to produce a more vigorous, fibrous root system which, in its turn, leads to a healthy growth above ground. It counteracts the weakening effects of excessive supplies of nitrogen, and helps to produce herbage of a much more nutritious kind. Finally, it quickens up the ripening processes in the plant, a useful and very real help with cereals in some circumstances.

All natural forms of phosphate are insoluble in water and therefore slow in action. There are two ways in which this drawback can be overcome in fertiliser practice. The raw material may be treated chemically in order to render it water soluble ; or it may be ground very finely by suitable mills in order to give it a greatly increased surface area on which the dissolving or assimilating influences in the soil and roots of plants can operate. Solubility in solvents such as citric acid or ammonium citrate is regarded as being almost equivalent to solubility in water as an indication of expected rate of action.

Superphosphate. This is the most widely used phosphatic fertiliser, chiefly on account of its high solubility in water and its rapidity of action. It has an acid reaction, and is considered by many farmers to be a contributory cause of acidity in soils, but expert opinion now regards its effects as being neutral. This fertiliser seems to give its best results in England on well-limed or only slightly acid soils. Generally speaking, it is the most useful form to use in all arable farming and especially on light and chalky soils. Superphosphate is a bulky, white, powdery or granular material consisting mainly of monocalcium-dihydrogen-phosphate and calcium sulphate in equal proportions. In the soil it probably passes rapidly to the dicalcium salt which, although no longer water soluble, is in a sufficiently fine state of division to be easily available to the plant. It contains 18–19 per cent P_2O.

Triple-superphosphate. This fertiliser first reached Britain in quantity during the Second World War and met with instant approval. It is now manufactured in this country. It is composed mainly of monocalcium-dihydrogen-phosphate, which is the active constituent of superphosphate. It contains 47 per cent of soluble phosphoric acid. In its behaviour it resembles superphosphate, of which it may be looked on as a pure form.

Basic Slag. This by-product of the steel industry still maintains its reputation in grass land improvement and on heavy soils. Changes in steel-making processes have led to the production of various distinct types of basic slag having very varied agricultural value, as careful experiments have shown. The old citric acid test as a criterion of the value of slags has now returned to favour, and at the present time much English slag can be obtained with a guarantee of very high citric solubility. Slags of low solubility are mainly derived from the " open hearth " process in which the phosphate is present as inert fluorapatite. The solubility in 2 per cent citric acid is a point well worth the attention of buyers, although slags of doubtful merit under this test are not necessarily to be despised. It may be worth while to point out that materials like slag, which are insoluble in water, depend largely for their success on a fine state of division and on thorough incorporation with the soil. To ensure results it is advisable to use a heavy dressing such as 8–10 cwt. per acre rather than 5 cwt. ; to choose a time when the ground is at its barest ; and to harrow the slag well into the soil. Where the surface of old grass land is covered with a mat of turf or excessive amounts of dead grass, careful attention to this point is essential, and drastic mechanical treatment is an essential part of the treatment. Slag should be ground sufficiently fine so that 70–80 per cent passes the prescribed sieve (viz. 100 wires to the linear inch). The presence of free calcium oxide and of calcium silicate confers a neutralising value on slag, making it almost equal weight for weight with ground limestone. While the phosphoric acid content can be as low as 8 per cent, it is usually 15–18 per cent.

Mineral Phosphates. There are several forms of this raw material on the market, all finely ground. They occur naturally as rock or gravels in many parts of the world. Imports into Europe come mainly from North Africa. They function in much the same way as basic slag and have the merit of a higher content of phosphoric acid (25–29 per cent P_2O_5), and a much lower price in comparison. Generally speaking, they are less reliable than slag, but in certain circumstances, such as in regions of high rainfall and on soils short of lime, they will often give as striking, if slower, results.

Silico-phosphate. This material, which is manufactured by incinerating mineral phosphate with sand and soda ash, was made on a small scale for a short time in 1945–6. It contained about 32 per cent P_2O_5 and gave results comparable with superphosphate in trials. It is insoluble in water but largely soluble in a solution of citric acid. Its manufacture has now been discontinued.

Dicalcium phosphate This material, intermediate in composition between superphosphate and mineral phosphate, has been the subject of critical field trials both in this country and elsewhere. In most localities, it has shown itself to be as valuable as superphosphate on an equivalent P_2O_5 basis. It contains 40 per cent P_2O_5.

Bone Products. Raw bones contain fat, gelatine, calcium phosphate and calcium carbonate. The fragments are extracted by various means, such as steam or solvents, to obtain the valuable fats and gelatine, and *Bone meal* is the residue after the extraction of the fat. It contains 21 per cent phosphoric acid and 4 per cent nitrogen, the gelatine not having been removed. The bone structure is still recognisable in the fragments. *Steamed bone flour* is the result of more drastic treatment; the gelatine being largely removed, the amount of nitrogen falls to 1 per cent, while the phosphoric acid rises to 28 per cent. At the same time the product is finer and more dusty than bone meal. The presence of the nitrogen and the difference in composition between the two forms are reflected in their prices. Much of the steamed bone flour produced nowadays is used by the manufacturers of animal feeding-stuffs. *Dissolved bones* vary according to their origin and contain about 15 per cent water soluble P_2O_5. They are made in similar manner to superphosphate by treating one or other of the above forms with sulphuric acid. The object is the same, namely, to render the phosphate soluble in water, though this conversion, owing to the technical difficulties, is only partially accomplished. The costs of bone products relative to the nitrogen and phosphoric acid they contain are high. The phosphoric acid of bone fertilisers, excluding dissolved bones which are now seldom met with, is only slowly available to plants.

Calcium Metaphosphate. This material, of U.S.A. origin, contains 64 per cent P_2O_5. Experimental tests show it to be a valuable source of phosphorus. It is not obtainable in Britain.

Guanos originate in districts of South America, and are the residues of the accumulated excreta of sea-bird communities. Their composition varies according to the amount of rain which falls in the locality. Guanos were among the earliest fertilisers to be imported into this country, and were highly valued not only for the phosphate they contain but also for their nitrogen and potash. Supplies are now very limited, and small quantities only are available here. They are so highly priced that their use is restricted to horticultural purposes. Average samples contain 7–10 per cent nitrogen, 9–13 per cent phosphoric acid, and 2 per cent potash.

The so-called fish guanos (or fish meals) are manufactured from unmarketable fish and their offals. Their composition is variable, with 7–8 per cent nitrogen and 4–8 per cent phosphoric acid. They are too expensive for general farm use, and are employed on horticultural holdings in the same way as meat and bone meals.

POTASH FERTILISERS

Potash as a plant nutrient nowadays receives much more attention that it used to do. In the plant it is found in stems and leaves more than in the grain, and its function is to help to establish and maintain the plant in a healthy growing condition. It is intimately connected with the assimilation process in the leaves and in the production of starch and sugars. This helps to explain its beneficial effect on quality of fruit, grain and tubers. Plants suffering from lack of potash show a dull blue colour in the leaves and often a characteristic marginal scorching. In cereals it often results in softness of straw and lodging. The range of potash fertilisers is small and the points of difference between the various kinds are not numerous. They are all easily soluble in water, but in the soil they are fixed by chemical reaction with the mineral complex and so are not liable to be washed out by rain, except probably in the lightest of sandy soils. The chief features of commonly used potash fertilisers are described later.

Chlorides, usually called muriates, constitute nowadays the chief bulk of the potash fertilisers. In addition there is still some sulphate of potash and small amounts of potash salts containing sodium or magnesium or both. Since for several high grade crops, such as tomatoes, the sulphate radicle seems to produce consistently higher quality than the muriate, sulphate of potash is the form preferred in horticulture. Potatoes show the same preference, but cost and supply must be taken into account ; there is no doubt that custom and use have veered almost completely in the direction of the muriate. The pre-war grades usually consisted of 20 per cent and 30 per cent potash salts, together with some 14 per cent kainit ; most of these are now unobtainable. One advantage accruing from the use of these lower grade salts was due to the common salt they contained. Their special beneficial effect on such crops as mangels and some grassland was doubtless due to the effect of the salt. In the former case the sodium acted directly as a nutrient, and in the latter the salinity stimulated grazing by the animals. Should low grade potash salts again be used, as indeed they may, it is as well to remember that on account of the high dressings usually given it is advisable to apply them well before seeding. Potash-magnesium salts are obtainable and are especially suitable for certain classes of land where a shortage of magnesium is evident. An interesting development associated with the increasing use of magnesium-free potash manures has been the associated increase of magnesium deficiency in field and glasshouse crops. While this development may be assumed to be partly due to this cause it is also well to remember that magnesium and potassium are mutually antagonistic plant nutrients, and the high use of one may have a depressing effect on the uptake of the other.

Muriate of Potash. This material is standardised to two grades. The higher grade contains a minimum of 60 per cent K_2O and is distributed in a free flowing form (Pink Flotation Potash) and runs easily through the manure distributor. Eighty per cent of the potash used falls into this grade. It has a common salt content of about 3 per cent. The lower grade containing a minimum of 50 per cent K_2O is also available and is in considerable demand. This grade contains approximately 14·5 per cent of common salt.

Sulphate of Potash. This material, which reaches the market in the form of a white crystalline powder, contains 48 per cent of K_2O and is now used almost exclusively for fruit, market gardens and for crops under glass.

Potash Salts. A still lower grade of muriate of potash is the salt containing 40 per cent K_2O. With the lower potash content there is a corresponding increase in the common salt present—21·2 per cent. It is commonly used on the Continent but in this country only to a limited extent.

Kainit. A small amount of kainit containing 16–20 per cent K_2O is brought through East Anglian ports for use on local crops of sugar beet. It is used as a source of salt as well as of potash.

Sulphate of Potash—Magnesia. An undoubted benefit which arose from the use of kainit coming from the Strassfurt deposits in Germany was due to its magnesium content. Following the cessation of its use several decades ago, many soils have become increasingly poorer in magnesium to the undoubted detriment of a number of crops. For this reason the reintroduction of potash fertilisers containing magnesium could be of considerable benefit. At the same time it is well to remember that magnesium and potassium are mutually antagonistic, so that the enhanced use of potash fertilisers may of itself have been a cause contributory to the development of symptoms of magnesium deficiency. Sulphate of Potash-Magnesia (26 per cent K_2O and 26 per cent $MgSO_4$) is now obtainable on our market. A similar product containing 40 per cent potash and 15 per cent magnesium sulphate, already used on the Continent, would seem to offer equal possibilities.

Flue Dust. Dusts which are collected from cement works, steel furnaces and from some other industrial sources may contain soluble potassium compounds which can be used as fertilisers. The composition is variable and may extend from 5 per cent K_2O to a figure as high as 15 per cent. Flue dust must be free from injurious substances and is usually used in the locality where it is produced.

Kelp. Kelp, or the ash of seaweed, has a potash content ranging from 12–16 per cent : its production is gradually dying in this country. As has already been mentioned earlier in this chapter, fresh seaweed is used as an organic fertiliser in many places around the coast of Britain, for as well as supplying humus it also contains about 1 per cent of potash. Three tons supply the equivalent of 1 cwt. of muriate of potash.

Wood Ash. While good quality wood ash may contain as much as 5 per cent potash, far less value attaches to material which has been leached by the rain.

Bracken is notoriously high in potash (40 per cent K_2O in the ash) and its value as compost ought well to compensate for the trouble taken to cut and prepare it.

COMPOUND FERTILISERS AND SPECIAL MIXTURES

Prior to 1939, manure merchants and many seed merchants sold different types of compound manures for various crops and for special purposes. Each one had its particular analysis and make-up. Stringent conditions during war-time were responsible for a great reduction in the number of mixed compounds marketed, with consequent reduction of confusion in the mind of the farmer. In recent years formulæ for several " national compounds " have been recommended and each compound is made up from a variety of constituents by different manufacturers.

Most fertilisers, straights and compounds, are now available in a granular or a free flowing form and have many advantages over powders. They are much more convenient to handle, and they flow more evenly through the drill. They do not absorb moisture so rapidly, and in consequence they do not cake or form hard lumps so readily during storage. When used as a top dressing they tend to bounce off plant foliage rather than adhere to it. They dissolve rather more slowly in the soil, giving a steady flow of nutrients over a longer period.

At intervals, controversies rage over the value of proprietary mixtures as compared with that of home-mixed simple fertilisers. It is for the buyer to make up his mind whether the difference in value, as assessed by unit values of nitrogen, phosphorus and potash, is serious enough to outweigh the undoubted merits of thorough mixing, granular condition and convenience for use which accompany the ready-mixed fertiliser. There is, however, room for speculation as to whether two proprietary turnip manures of widely differing analysis can both be equally effective. More often a preference for one or the other is the product of fancy rather than fact. Quality rather than variety is probably of far greater importance provided both manures contain high-quality ingredients. A possible exception may be found in the preference shown by market gardeners for fertilisers containing organic materials. These are slower acting and therefore yield nutrients over a longer period, and in addition add to the water-holding capacity of the soil·

Concentrated Two- or Three-Constituent Fertilisers. There is now on the market a range of concentrated fertilisers containing two or three of the main food nutrients in much greater concentration than is possible in mixtures of the older single-constituent fertilisers. This has been achieved by bringing the nutrients together in one compound, thus eliminating less valuable carrier materials. For instance, nitrate of soda contains nitrogen attached to a soda base, while sulphate of potash contains potash attached to a sulphate radicle. These two fertilisers have money values to which the soda in the former and the sulphate in the latter contribute little or nothing. Chilean potash nitrate, on the other hand, contains 10 per cent potash and 15 per cent nitrogen, both the potash and the nitrogen being readily available to plants. Chilean potash nitrate is actually a mixture of potassium nitrate and sodium nitrate, and the combination of the two fertilising ingredients makes it a popular material for market garden work. From materials such as ammonium phosphate, ammonium nitrate, urea, triple-superphosphate, sulphate of ammonia and muriate of potash, concentrated fertilisers can be produced comparatively easily : they can be mixed with each other to give a complete manure of almost any desired analysis, in a convenient granular condition, perfectly blended, easy to handle and store, readily available and without undesirable bulk.

Designation of Compound Fertilisers. The bewildering number of compound fertilisers offered to farmers and growers has led to a simplified list within the National Agricultural Advisory Service, from which recommendations are made. The fertilisers are designated by the percentage of nutrients they contain and by the relative proportion of those nutrients ratios, as shown in Table 4.

TABLE 4

SIMPLIFIED LIST OF COMPOUND FERTILISERS

Class.		Nutrients as percentages.			Plant Food Ratio.		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O
N.P.K. . . .	*a*	10 12	10 12	15 18	1	1	1½
	b	6	15	15	1	2½	2½
	c	9	6	18	1½	1	3
	d	12	8	8	1½	1	1
	e	8	12	8	1	1½	1
N.P.	*f*	9	18	0	1	2	0
N.K.	*g*	16	0	16	1	0	1
P.K.	*h*	0	10	20	0	1	2

The opinion is held that, by choosing appropriately from this list supplementing where necessary with straight fertilisers, the needs of all agricultural and horticultural crops can be met.

If the recommended fertiliser is one that does not occur in the list of a particular manufacturer or merchant then that most nearly approximating in composition to it can be taken.

Mixing Fertilisers. Compound or ready-mixed fertilisers are usually prepared by manufacturers who are well used to the difficulties which arise from mixing. Their products can be relied upon to reach the farmer in a good condition and to keep for a reasonable period. Inexperienced persons are advised to take care when mixing for the first time. Certain fertilisers, such as those containing the ammonium radicle and others containing free lime (basic slag, calcium cyanamide, etc.), if mixed, will liberate gaseous ammonia and lose much of their fertiliser value thereby. Some materials containing superphosphate are liable to set hard unless a " drier " such as steamed bone flour or granular peat is incorporated. On account of the possible presence of free acid, superphosphate should not be mixed with fertilisers containing nitrates (nitrate of soda, etc.). Farmers and others mixing their own fertilisers are advised to sow them the same day if possible, or at any rate within a period of twenty-four hours.

RECOMMENDED DRESSINGS

The amount of fertiliser actually to be applied will depend on a number of factors.

1. The general nutrient requirements of the crop to be grown.
2. The special requirements of the soil type. This will vary, as the type may be a sand, a heavy loam, a chalk soil or a peat.
3. The level of fertility of the soil. Should the soil be rich or poor in one or more nutrient, then the dressing and type of fertiliser will have to be adjusted to suit. Such adjustments are constantly being made in recommendations in the light of chemical analysis and experience.

4. The quantity and type of fertiliser are also subject to climatic variations. For example, the needs of the potato crop are rather different on the wetter side of the country from those in the drier eastern parts.

Amount of Fertiliser to Apply. It is customary to make recommendations for applications in terms of hundredweights per acre. Thus the recommendation for a main potato crop may be to apply 12 cwt. per acre of a 10–10–15 mixture or, alternatively, 10 cwt. per acre of a 12–12–18 mixture. Either supplies the same weights of nutrients. These mixtures were chosen as having the nutrients present in the right proportions—1 : 1 : 1½—to suit the main potato crop.

If, from analysis or otherwise, a soil is known to be rich in any particular nutrient, for instance phosphate, then a fertiliser with another suitable ratio may be chosen. Such a fertiliser could be type (*c*), 9–6–18, whose ratio is 1½ : 1 : 3. If this were applied at the rate of about 12 cwt. per acre it would be suitable, albeit supplying rather more potash than is required ; absolute accuracy is neither possible nor necessary.

The Unit System. A method which is rapidly gaining favour among farmers and those advising them is the unit system. The *unit** is defined as one per cent of a cwt., or 1·12 lb. This is the unit used in discussing the manuring of crops in Chapters IX and X. The unit can be used when recommending quantities both of straight fertilisers and of compounds.

With this method the number of units of a particular nutrient in one cwt. of a fertiliser is the same as the percentage of that nutrient in the fertiliser. Thus one cwt. of sulphate of ammonia having 21 per cent of nitrogen contains 21 units of nitrogen (N) : one cwt. of 18 per cent superphosphate contains 18 units of phosphoric acid (P_2O_5) : and one cwt. of 60 per cent muriate of potash contains 60 units of K_2O.

Putting it another way, the stated percentage of an ingredient printed on the one-cwt. bag of fertiliser is also the number of units in lb. in the bag. A cwt. bag of a 12 : 12 : 18 compound fertiliser contains 12 units of N : 12 units of P_2O_5 : 18 units of K_2O.

The following example shows how the system can be used in choosing a suitable compound fertiliser. Suppose a farmer has been in the habit of using the following amounts per acre of straight fertilisers for his potato crop :

5 cwt. sulphate of ammonia (21 per cent N)
5½ cwt. superphosphate (18 per cent P_2O_5)
2½ cwt. muriate of potash (60 per cent K_2O)

He wishes to save the trouble of mixing these straights by using a compound fertiliser. How does he choose a compound which will supply the same total amount of nutrients in the same proportions ?

The quantities of the respective nutrients expressed as units would be :

$$\text{N } 5 \times 21 = 105 : P_2O_5 \ 5{\cdot}5 \times 18 = 99 : K_2O \ 2{\cdot}5 \times 60 = 150$$

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* This basic quantity is sometimes printed in capitals, thus : UNIT, to distinguish it from the unit, $\frac{1}{100}$ ton or 22·4 lb., used in comparing fertiliser prices (see p. 189).

He then examines his fertiliser price lists and chooses a compound having the three nutrients roughly present in the same proportions (or ratio) viz : 1 : 1 : 1½. He may find several quoted in this ratio, viz : (*a*) 7 : 7 : 10½ ; (*b*) 10 : 10 : 15 ; or (*c*) 12 : 12 : 18.

It only remains to calculate the particular one he chooses, in this case (*c*), in cwt. per acre : thus the amount of compound containing 105 units of nitrogen will be $\frac{105}{12} = 8\frac{3}{4}$ cwt. This quantity will at the same time contain approximately the amounts of P_2O_5 and K_2O. he requires.

The system is flexible and the requirements of crops can be stated directly in terms of the numbers of units per acre required. It can also be utilised for stating the amounts of ingredients in farmyard manure and other similar products: for example 10 tons of average F.Y.M. can be said to contain 100 units of N, 60 units of P_2O_5 and 100 units of K_2O.

The Optimum Dressing. The most economic dressing is that which will give the most profitable return per acre. This is based on field experiments and a knowledge of the response curves obtained therefrom. Such knowledge must, of necessity, be of a general nature and take into account the cost of the fertiliser and the monetary value of the crop. If the cost of the fertiliser at different levels be plotted against the return from the crop, it will be found that at first the curve rises steeply but later flattens out. This shows that with each of the later increments of fertilisers there is a progressively lower return. The optimum point is not well defined but is usually sufficiently clear to guide the farmer. Optimum dressings are discussed later on when individual crops are described.

UNEXHAUSTED MANURIAL VALUES

The varied availability and mode of action of plant nutrients in farmyard manure and fertilisers are recognised in the practice of valuation for compensation for materials used on the farm on the occasions when it changes hands. Purchased feeding-stuffs contain considerable manurial constituents (see Appendix III). It is the practice to value on the assumption that 30 per cent of the nitrogen and 50 per cent of the water soluble phosphoric acid and 66 per cent of the potash are found in the manure, and that the effect of these is spread over several seasons. These assumptions, together with the analysis of the feeding-stuff and the unit values of nitrogen, phosphoric acid and potash, in the fertiliser market give the compensation value per ton of the feeding-stuff consumed. The losses are assumed to depend on the kind of stock on the holding and the conditions under which it is kept. Similar reasoning may be followed in the case of straw sold off the farm, but in this case a figure has to be arrived at for the value of straw more as regards its physical effect in farmyard manure than on its chemical composition. In the case of purchased fertilisers, the subject is more difficult on account of the lack of satisfactory experimental data and the needs of varying soils and crops. One may encounter all ranges between the extreme cases of 1 cwt. of sulphate of ammonia with no residual value, and 80 loads of chalk with effects lasting several years.

THE APPLICATION OF FERTILISERS

The Placement of Fertilisers. Placement of fertilisers has, of recent years, been the subject of much experiment by comparing it with the traditional method of broadcasting. The word placement in effect refers to two methods of application. Firstly, by the use of a combine drill with hoppers which, although separately holding the seed and the fertiliser, actually sows them together down one spout and, secondly, by means of placement drill which sows them separately so that the fertiliser lies in a band near, but not necessarily touching, the seed. The theory behind either method is that the fertiliser is placed near the germinating seed and because it is not mixed with the soil escapes fixation and remains available for a longer time. This process of fixation referred to applies mainly to the phosphates and only to a lesser degree to the potash. It hardly applies at all to the nitrogen, since, even if this is given in an ammoniacal form it soon reaches the condition of nitrates which flow freely in solution through the soil.

Of the fertilisers used for placement, superphosphate is the commonest and safest. Experiments with cereals have shown that 1½ cwt. per acre superphosphate placed have an equivalent effect on yield as 3 cwt. per acre broadcast.

Potash fertilisers are also placed, but since they are freely soluble in water may, under dry soil conditions, cause damage to cereal seedlings if used in too large amounts. The purer the potash fertiliser the less will be needed and consequently the less will be the risk of scorch.

Liquid Fertilisers. There is some tendency, probably an increasing one, to apply fertilisers in a dissolved condition. Two outstanding examples of this form of application are, one, the supply of trace elements such as molybdenum and copper to deficient crops in the form of sprays and, two, the supply of nutrients such as potash-nitrate in a dilute form through overhead irrigation systems.

PURCHASE OF FERTILISERS

A purchaser of fertilisers is nowadays fairly adequately safeguarded by law. The Fertilisers and Feeding Stuffs Act operates to ensure his being supplied with an adequate description of the nature and analysis of most manures, and provides him with the means of obtaining satisfaction in cases of dispute. According to the class of fertiliser offered, the vendor is required to supply information regarding its percentage composition of nitrogen, phosphoric acid soluble in water, insoluble phosphoric acid and potash. The vendor is allowed limits of variation in his figures to set off against the inevitable deviations in the composition of various substances in bulk. For instance, the description of a basic slag as containing 12 per cent phosphoric acid and 90 per cent passing the prescribed sieve is adequate to cover a range of 11–13 per cent phosphoric acid and 85·5–94·5 per cent fineness.

Comparative Values. It is useful to be able to compare prices with analysis, as this affords a criterion of comparative values, although, as had been pointed out, it is unfair to press the argument too far.

A glance at a price list or market report shows very great variations in the prices per ton of different classes of fertilisers. Nitrogenous manures as a whole are the most, and potassics usually the least, expensive. The Fertilisers and Feedings Stuffs Act gives a description of most of these commodities in terms of the amount of the main fertilising constituents which they contain, i.e. nitrogen—N, " phosphoric acid "—P_2O_5, and " potash "—K_2O, expressed as percentages. One per cent of a ton, or 22·4 lb., is usually taken as a convenient " unit " on which to compare prices ; thus, 1 ton of sulphate of ammonia (20·8 per cent nitrogen) contains 20·8 units of nitrogen, and 1 ton of " Nitro-Chalk " (15·5 per cent nitrogen) contains 15·5 units of nitrogen. Allowing for the subsidy at present payable on nitrogen, the prices of these two commodities to the farmer are respectively £11 4*s*. and £11 5*s*. 6*d*. per ton, the cost per unit of nitrogen is 10*s*. 9*d*. in the former and 14*s*. 6*d*. in the latter.

The system of unit prices provides a useful criterion of values, but to make it the final or sole test of worth is unsound for the reason that there are other differences of practical importance which may considerably modify comparative values assessed solely on unit price. In the case of the two materials cited above, for instance, the higher cost per unit of nitrogen in nitro-chalk may be offset by its presumed special value as a top dressing on soils lacking a satisfactory reserve of chalk, and in its containing the quicker acting nitrate as well as the slower-acting ammonia. Most fertilisers have their individual peculiarities which give them their highest value for some particular set of circumstances, and in these cases the unit prices of their constituents loses its importance and may become, in fact, a minor consideration. As indicated, the concept of unit values may be used for making comparisons of the cost of similar fertilisers when other factors may be presumed to be equal.

When assessing the value of compound manures containing several nutrients it is necessary to adopt the unit values of the constituent nutrients by reference to well-known straight fertilisers. For instance, in order to compare the relative values of two compound fertilisers, A being a 9–9–15 type and B 9–6–18.

The unit cost of N in sulphate of ammonia is taken as 10*s*. 9*d*., the unit cost of P_2O_5 in superphosphate as 9*s*. and the unit cost of K_2O in muriate of potash as 6*s*. 6*d*. Their relative values are calculated as follows :

Fertiliser.	N	P_2O_5	K_2O	Total.	Quoted Market Price.
A per ton*	9 × 10*s*. 9*d*.	9 × 9*s*.	15 × 6*s*. 6*d*.	£13 15*s*. 3*d*.	£18 10*s*. 6*d*.
B per ton*	9 × 10*s*. 9*d*.	6 × 9*s*.	18 × 6*s*. 6*d*.	£13 7*s*. 9*d*.	£19 7*s*. 6*d*.

* All prices shown are with the subsidy—where payable—deducted.

The totals give a good indication of the relative monetary values of the two compounds. If a check on the market values is to be made, then some allowance must be made for the cost of mixing and marketing, a figure which in some cases may be much above that shown. For making a direct comparision of the market quotation of a compound with the cost which a farmer may incur by buying straight fertilisers and mixing them himself, a small sum to cover mixing is usually added. In many cases it will be of considerable financial advantage for a farmer to mix his own fertilisers, especially if he is in a sufficiently large way of business to warrant buying straight fertilisers in bulk ; but against this must be balanced the merits of ready-mixed fertilisers, such as their ability to keep longer, their granular condition, convenience, etc.

MATERIALS FOR LIMING THE SOIL

In the section dealing with soils the subjects of soil acidity and calcium deficiency were dealt with at some length. There are several commodities available for correcting these deficiencies and their value is now generally expressed in terms of their neutralising value (N.V.) The production and the use of lime has been extended during the last two decades and now reaches 6–7 million tons per annum of lime products of all kinds. This is equivalent to 3·2 million tons of CaO.

Chalk. Over considerable areas of the country chalk deposits are accessible and extensively worked. Rough chalk is still being dug and spread on the land, but nowadays only to a limited extent. The usual application of this rough material is at the rate of about 20 tons per acre. The chalk contains 90 per cent or more of calcium carbonate and only the softer forms weather down at all rapidly. Crushed chalk is more useful than the rough forms and can be applied at correspondingly lower dressings. This material is now being extensively dried in rotary driers and kilns and much of it is then finely ground. The specification for this ground chalk is that it shall all pass through a ¼ in. sieve and about 40 per cent through the 100 mesh sieve. It is sold as ground chalk or ground carbonate of lime. In addition there is a coarser material known as screened chalk available in some districts and applied at rates varying from 4–10 tons per acre.

Ground Limestone. This is another form of ground carbonate of lime produced from the harder limestones. Prior to 1939 it was thought necessary to grind limestone to a degree of fineness comparable with basic slag. The greatly increased demands for its use both during and after the war has caused the question of fineness to be examined critically by means of field experiments. As a result it is now agreed that it should be ground to such a condition of fineness so that at least 40 per cent passes the 100 mesh.

Waste Limes are usually in the form of calcium carbonate produced in a very fine state of division in various industrial and water-softening processes. Formerly much of it was dried and commanded a very high price amongst some intensive growers. Waste limes may contain up to 95 per cent or more of calcium carbonate, but usually contain much less. They can sometimes be obtained moist from beet and other factories at a nominal cost when, provided that they do not need to be carted far, they prove a most useful form of lime, as favourable weather after leading will dry out the heaps and enable them to be spread easily.

Burnt Lime is still produced extensively and represents the form with the highest neutralising value. It is composed of calcium oxide containing residues which were present as impurities in the limestone from which it was derived ; these do not amount to more than a few per cent in the purest samples. Little is now used on the land in the coarse lump form. Instead much of it is kibbled, the product having a maximum diameter of about 1 inch ; in this form it can be spread mechanically. Ground burnt lime in bags is still produced but is more expensive than the kibbled form. It must not be stored long since it rapidly absorbs moisture and bursts the bags.

Hydrated Lime. High-grade slaked lime in a finely divided condition is usually available to, and popular with, horticulturists. It is rather expensive compared with other forms of lime, but can be intimately mixed with dry soils with consequent rapid action.

Lime Screenings. At a number of present day lime-burning works, air slaked residues known as lime screenings are available. They are very like burnt lime in their effect, bearing in mind their poorer analysis and uneven texture.

Magnesian Limestone and Lime. There is a growing production both of ground magnesian limestone and its burnt equivalent. Its increased demand probably arises from at least two causes. Firstly, considerable areas of soils now exist where lime is not only needed to neutralise acidity but also where added magnesium is required as a nutrient for the crops ; secondly, for application to grassland where it is thought that its presence will help to overcome hypomagnesaemia in animals.

Quantities of Lime to Apply. The quantity of lime to apply varies with a number of factors. In general, the smaller dressings are needed on light, sandy soils of slightly acid nature. Applications will increase with increasing acidity, and with increasing amounts of clay and organic matter in the soil. The maximum dressings are demanded on strongly acid peats. When initial acidity has been corrected an occasional dressing of a ton of ground limestone per acre, or half a ton of ground lime per acre, applied every four or five years should maintain the soil in a sound, healthy state of fertility.

MISCELLANEOUS FERTILISERS

Besides the materials already described, some mention must be made of those supplying trace elements, and of salt.

Manganese Sulphate. This is usually applied in a calcined form to supply manganese on areas where manganese deficiency is established. It may be applied in the ordinary way at the rate of ½–1 cwt. per acre, or as a solution in the form of a spray (10 lb. per acre dissolved in 100 gallons of water).

Borax. This material can be applied in the form of a solid dressing to the soil before seeding (14–20 lb. per acre), or in the form of a spray. In either case its application is to overcome boron deficiency in soils leading to such diseases as "Heartrot" in sugar beet and "Raan" in swedes. Boronated fertilisers can now be obtained to be applied at a rate designed to supply about 20 lb. borax per acre.

Copper Sulphate. Copper in the form of copper sulphate can be applied as a spray or as a solid application.

Magnesium Sulphate and Dolomitic Limestone. Magnesium deficiency can be corrected by application of solid magnesium sulphate (1–2 cwt. per acre), or by a dressing of magnesium limestone or dolomite applied in the seed bed, or by 3 per cent sprays of magnesium sulphate. In glasshouses, much heavier soil applications (20 cwt. per acre) of magnesium sulphate have been used successfully.

Salt. Common salt has been used for many years on a variety of crops, particularly mangels, barley and carrots. More recently it has been used with success for sugar beet and has been proved, on many soils, to be a substitute for potash fertilisers. It is applied in quantities of 3–5 cwt. per acre in the seed bed, preferably fourteen days or so before the seed is sown. Certain crops show a strong dislike to applications of salt, probably due to the deleterious effect of the chloride radicle rather than to the sodium present, and it would be wise to avoid indiscriminate application.

FUTURE TRENDS IN FERTILISER PRODUCTION

The most likely trends in production of fertilisers probably lie in conditioning, granulation, and concentration. The ideal fertiliser should be in such a condition that it stores well over long periods without becoming caked ; should be in a granular condition—probably in the 1–5 mm. size range, so that it will flow freely through drills and yet break down readily in the soil. (Incidentally the working parts of the drills themselves should be made of materials which will not corrode and which can easily be removed for cleaning.) It should be concentrated so that the cost of transport and rate of application can be kept as low as possible.

Recent years have seen much progress in the concentration of N, P and K on the lines already mentioned. But it should be possible to go further still by using such substances as ammonium nitrate, urea, potassium phosphate, ammonium phosphate, etc. Just as anhydrous ammonia has already passed into commercial use in some countries, highly concentrated compounds of nitrogen and phosphorous may have a future.

As an example of progress in the field of concentrated fertilisers mention should be made of the nitrophosphates, materials which in this country reached the experimental manufacturing stage during the period when sulphur was in short supply. Trial batches were made and extensive field trials set in hand to test its value. Experiments were carried out comparing this material with similar compounds of Dutch and French origin and at the same time its efficiency alongside the more conventional fertilisers as superphosphate and sulphate of ammonia. The results can be summarised thus: all three nitrophosphates were inferior to superphosphate for potatoes but they were more effective on acid soils than on neutral soils. Their superphosphate equivalents calculated from the average results for the potato experiments were: British product, 78 per cent; French product, 62 per cent; Dutch product, 33 per cent. For grassland, all three products gave lower acreage yields than superphosphate supplying only two-thirds as much P_2O_5. For swedes, the nitrophosphates were practically equivalent to superphosphate and all three behaved similarly. Somewhat variable results were obtained over three years and it is probably fair to conclude that the P_2O_5 in nitrophosphate is about three-quarters the value of water-soluble P_2O_5.

Chapter VIII

CROPPING, IRRIGATION AND WEED CONTROL

PRIMITIVE tillage farming in all parts of the world is, and in the past has always been, associated with a simple sequence of cropping. In the typical case a section of grass or light scrub-covered land is cleared and cropped with the same or similar crops until it ceases to yield profitable returns, either because of the exhaustion of fertility or because of the accumulation of weeds. In the former case the cultivators move on and break up another virgin area ; in the latter the same practice may be adopted or a bare fallow may be introduced to kill the weeds, after which the land is cropped as before. The former practice was probably adopted in primitive times in Britain. The latter practice was typical of the farming in California when wheat growing was first developed in that country during the latter part of last century. It is equally typical of certain types of farming in the Prairie provinces of Canada where continuous cereal crops are interrupted by bare fallows. As the needs of a community increase and farming becomes more intensive some definite sequence is developed ; thus in the Manorial period of this country, " when each man had his rood of land ", the three-field system was developed. In this, autumn corn was followed by spring corn, followed in the third year by a bare fallow after the stock had grazed the stubble of the previous crop through the winter and spring periods.

At this period of British farming, when the fields were divided into a series of narrow strips, each occupied by a different cultivator, the need for a rigid yet simple rotation was paramount, since every field would have become a patchwork of crops if each cultivator had been allowed to crop his " lands " as he pleased. When Enclosure followed, the need for a rigid system of cropping for purposes of maintaining fertility still persisted, though to a lesser degree, and with the introduction of clover by Sir Richard Weston, turnips by Lord Townsend and the drill husbandry by Jethro Tull, the four-course system was developed and thereafter formed the basis of English farming until the end of the nineteenth century. During the latter part of this period the introduction of many types of artificial manure, and the knowledge of how to use them, rendered the rigid four-course rotation no longer necessary for the purpose of maintaining fertility, and the Agricultural Holdings Acts of 1908, giving tenant farmers freedom of cropping, finally overthrew the idea that a rigid rotation was essential to arable farming. The introduction of the farm tractor, giving much greater speed of manipulation of tillage operations, further reduced this necessity.

At the present time most arable farmers follow no fixed rotation. Tremendous developments have taken place in British agriculture in the last two decades following the stimulus of the outbreak of the Second World War. Better varieties of crops and their improved protection by seed dressings, herbicides, fungicides and insecticides ; widespread use and better understanding of chemical fertilisers ; the decline in manpower ; and above all the vast impact of mechanisation, have rendered a fixed sequence of cropping less necessary, and often less desirable. Farming has become more specialised, and the term " sequence of cropping " implies a greater flexibility to meet changing conditions in competitive farming, than does rotation of crops. Nevertheless, the main objects of rotations still apply.

OBJECTS OF ROTATIONS

The objects to be attained by a definite sequence of cropping may be considered under the following headings :

(1) The farming system in relation to land, labour and capital.
(2) The increase or maintenance of fertility.
(3) The economical distribution of labour through the year.
(4) The suitability of crops to the farming system.
(5) The degree of specialisation.
(6) The control of weeds.
(7) The control of plant diseases and pests.

1. **The Farming System in Relation to Land, Labour and Capital.** Farming conditions vary widely and the sequence of cropping must be varied accordingly. Climate is an important factor to be considered in deciding what crops to grow. The dry climate of the eastern counties is favourable to tillage farming and especially to the cereals, wheat and barley. The moister and cooler districts of the west and north are more suitable to the growth of temporary and permanent pasture and, if cereals are grown, to oats rather than wheat or barley. Smaller differences in local climate, as for example those associated with altitude, aspect, liability to frost, etc., may favour the growth of one crop and make it advisable to vary the sequence.

The character of the soil is largely responsible for the success or failure of different crops. On light soils with easy drainage the land warms up quickly in spring, growth is rapid and harvest is early. Tillage and intercultivation are comparatively easy and root growth is facilitated. On the other hand, fertility is not generally very high, and in periods of dry weather crops may suffer from lack of water. These conditions are specially favourable for the growth off malting barley, provided the land is not too dry. They are not so favourable for wheat and oats, but rye grows to advantage on the lightest and driest of soils. Root crops of all descriptions can be easily cultivated and easily harvested or folded if desired. Such soils are specially favourable for sugar beet, turnips, and to early potatoes. They are not so suitable for main crop potatoes because lack of fertility and of moisture frequently result in small crops. Light soils, especially in moist districts, are favourable for catch cropping because seed-beds can be quickly obtained, and growth is rapid. Chalky soils are frequently light and easy to cultivate, in which case they favour the growth of barley and roots and in addition such leguminous crops as peas, sainfoin and many clovers.

If the soils are shallow they are not very suitable to wheat, beans or potatoes.

Heavy soils are difficult and costly to cultivate. Their texture does not facilitate the production of good seed-beds nor the easy growth of plant roots. They are not favourable for the harvesting of root crops in bad weather. As a result of these conditions relatively few crops can be successfully grown upon them, and the crops which can be successfully grown are generally possessed of a vigorous root system. Wheat and beans both have strongly growing roots and these crops grow to advantage on clay soils. Mangels have deeply penetrating roots and grow well on clays, but potatoes cannot be grown successfully because the soil is unsuitable for growth and because it is impracticable to harvest them in wet seasons. Red clover and white clover, together with certain grasses used in temporary pasture such as rye grass and cocksfoot, grow freely and abundantly provided the land is not allowed to become waterlogged ; since such pastures entail little annual expenditure for labour and management they can be grown economically upon heavy land. Loamy soils are suitable for the growth of nearly all crops because both fertility and water supply are generally good and the crops produced are generally large. Both barley and wheat grow well, as do beans, and large crops of good quality potatoes can generally be produced. Very large crops of turnips and mangels can be grown, though the folding of the former in wet weather sometimes damages the texture of the land. Red clover and other leguminous crops grow freely and many vegetable crops can be incorporated in the sequence of cropping. For these reasons it is necessary in planning a sequence of cropping to give careful consideration to the suitability of the crops to the soils on the farm.

The stock policy adopted on the farm will make varying demands for food and bedding, especially for the winter months, and the cropping sequence will need to be framed to provide for these. If sheep predominate, a sequence of folding crops, roots, kale or temporary leys must be provided. If dairy cows, a winter supply of hay, mangels, silage and such winter-green crops as marrow kale may be required. Provision must be made to guard against periods of shortage of grass during summer droughts by the growth of lucerne, green maize, cabbage, kale, rape or a reserve of silage. Conversely, the amount of stock kept and the amount of farm-yard manure produced may influence the sequence of cropping by rendering it advisable to introduce a larger area of potatoes, green vegetables, etc., to make more profitable use of this manure.

When the farm is considered as a unit the amount of land, labour and capital available will determine the farming system. If land is the limiting factor, intensive cropping is likely to be practised. Where labour is scarce, grass and cereal crops will be preferred to the more labour demanding root crops.

Local markets and local demands for special produce may make it desirable to vary the sequence of cropping. Proximity to a large provincial town or to a seaside resort will create a good demand for vegetables of all sorts which can be cheaply delivered if the distance is short. In such cases these crops should find a place in the sequence. Proximity to racing stables will create a good demand for hay and straw. Proximity to a sugar factory reduces the cost of transport on sugar beet, especially if the fields on the farm adjoin the main road or canals. In such cases the sequence of cropping should be planned accordingly. In other cases, where farms and fields are inaccessible for one reason or another, provision should be made in the sequence of cropping for a greater proportion of the produce to be fed to stock, or for the growth of crops which are not bulky in character so that transport is facilitated. These and many other considerations peculiar to the circumstances must be taken into account when planning the sequence of cropping on any farm.

2. The Increase or Maintenance of Fertility in the Soil. Whether it be considered from the point of view of the nation, the owner, the occupier or the farm worker, there is no condition (except that the farming system is attended with profit) of greater importance than that the fertility of the land be maintained or increased, because upon this mostly depends the power of the soil to produce future crops.

Fertility of the soil, in the sense in which the word is here used, is governed firstly by the supply of humus and the nitrogen which it contains, and secondly by the supply of certain available minerals, especially lime, phosphates and potash. All soils, whether they be cultivated or uncultivated, are continuously undergoing change brought about by chemical, physical and biological actions. Some of these changes lead to an increase of fertility, others to a decrease. The sum of the changes in ground covered with vegetation and not cultivated generally leads to an increase of the humus, and therefore to increased fertility. Under arable conditions the sum of the changes generally results in loss of humus and therefore in reduced fertility.

Most tillage operations tend to increase the aeration or ventilation of the soil so that oxidation is encouraged. By this the humus is decomposed and the nitrogen which it contains converted from an insoluble to a soluble form. In this condition it is available for absorption by plant roots. At the same time, tillage and the consequent aeration of the soil tends to encourage the solution and availability of the mineral plant food in the soil. Plant foods, when in this soluble condition, are liable to loss in two ways ; either they may be absorbed by plant roots to form part of the structure of roots, stems, leaves or fruits of the plants growing in the soil, or failing this, they may be carried away in solution by the excess rain-water draining through the land. In the former case such parts of the plant as are removed from the field at harvest result in loss to the field of the plant-food elements which they contain, whilst other parts, such as roots, stubble, broken leaves, etc., are left on the field to be reincorporated in the soil, together with the plant food they have taken up from it.

When crops are consumed by stock on the field a comparatively small portion of the elements of plant food is retained in the structure of the animals, and the greater part is returned in the fæces or in the urine to the land. In the same way when harvested crops are consumed in the yards by stock bedded upon straw, the resulting farm-yard manure contains a large portion of the plant food removed in the crops consumed and used as bedding, and if the manure is carted back to the land it returns to it the plant food which it contains. In the making and storage of farm-yard manure, however, it must be remembered that considerable losses of nitrogen and smaller losses of minerals are liable to occur, so that the efficiency of the return of plant food is not so great by this method as when the crop is consumed on the land where it is grown. It will thus be seen that loss of fertility is greatest in the case of those crops such as cereals or potatoes which may be sold away from the farm, intermediate in the case of crops which are consumed in the yards and made into dung (provided the dung is subsequently returned to the land), less in the case of crops consumed on the land, and least of all in green crops which are ploughed back in to the land where they are grown.

Some crops, either because of the greater penetrative power of their roots or because of the more efficient tillage which they receive, extract from the soil larger amounts of plant food than others. A comparison in this respect between barley and mangels shows that the latter extracts from the soil very much larger amounts of plant food than the former and is to this extent more exhausting. Root crops generally require, and do in fact extract from the soil, considerably larger quantities of plant food than cereals. Root crops, however, are generally heavily manured and frequently consumed by sheep on the fold, so that the fertility of the land is increased during the root break. For this reason root crops are generally regarded as renovating crops ; whilst cereals are exhausting crops because they are not heavily manured and because the whole crop is removed from the field. Leguminous crops in like manner extract from the soil more mineral plant food than the cereals and in this respect are more exhausting crops. They also obtain very much larger quantities of nitrogen than the cereals—a 2-ton crop of clover hay will contain approximately four times the amount of nitrogen contained in a wheat crop consisting of 17 cwt. of corn and 30 cwt. of straw—but the nitrogen of the leguminous crop is mainly obtained by the nodules on its roots, not from the soil itself, but from the air in the soil. This greater accumulation of nitrogen, therefore, by leguminous plants does not result in loss of fertility, but on the contrary is a most potent means of accumulating fertility. When the roots and stubble of such crops are ploughed back into the soil, and still more when the stems and leaves are consumed on the land, the nitrogen content of the soil is largely increased. The growth of peas and beans under arable conditions, and of white clover under pasture conditions, thus leads to large accumulations of nitrogen in the soil.

3. The Economical Distribution of Labour through the Year. In framing a sequence of cropping the economic use of labour requires to be considered not only from the point of view of the distribution of labour through the year, but also with regard to the elimination of unnecessary or unproductive work.

In farming practice it is generally necessary to employ the greater part of the labour continuously throughout the year. It is not so feasible in farming as in other businesses to discharge men when a busy season of work is finished and expect to find them available for work when the busy season comes on again. If such methods are attempted it will be found that casual labour is either very inefficient or very costly. Continuous employment must, therefore, be found for the greater part of the labour employed. Now no single crop requires continuous labour throughout the year, but each crop requires labour, and sometimes a great amount of labour, at special seasons. Thus the wheat crop in this country is planted in autumn and harvested in late summer, and therefore demands labour mainly during October and November for planting and in August and September for harvesting. Very little labour is expended on the crop at other seasons. The potato crop has requirements for labour at other seasons ; the land may be ploughed in winter, planted in spring, cultivated and sprayed in early summer, harvested in autumn and marketed in winter. It will be seen that these two crops require labour at dissimilar periods, and for this reason are suitable crops to combine in a sequence of cropping. Other crops have their own seasonable requirements of labour. In framing a sequence of cropping, therefore, great care must be given to see that too great a congestion of work does not arise at any one period of the year, for nothing prejudices successful farm management so badly as being unable to do work at the right time. Conversely, things must be so arranged that the periods when little or no labour is required are not too protracted. A certain amount of labour can generally be economically utilised upon matters of upkeep such as drainage, fences, roadways, etc., which do not require attention at very precise times, but these are limited in quantity, and any excess of labour beyond these requirements is unproductive.

Another point in the economical utilisation of labour is illustrated in the cartage and use of farm-yard manure. At the present time the cost of labour involved in the cartage and spreading of this product is very high. If the dung is utilised for the production of crops which are saleable at good prices all is well, but if it is utilised in the maintenance of fertility for the production of ordinary farm crops such as wheat and beans the cost may bear no relation to the benefits received, especially when the field lies a long distance from the site where the dung is made. A sequence of cropping which involves the carting of farm-yard manure for ordinary farm crops must so far as possible be avoided, and in its place the fertility of outlying fields should be maintained either by the use of green manuring or by the use of temporary pastures which are grazed during part of the year.

4. The Suitability of the Crops to the Farming System. Technical and scientific developments have led to a much greater freedom in cropping. Inherently infertile light land may be improved by the use of lucerne and cocksfoot leys, irrigation and subsequent heavier stocking. Heavy land may yield to powerful mechanisation and produce crops previously considered unsuitable. None the less there remain important differences in the response of crops to environmental conditions of soil and climate.

Each successive crop should allow sufficient time to carry out the necessary tillage operations in order to prepare an adequate seed-bed. The interval should not be too long nor too short. If too long, not only is time wasted but soluble plant food may be drained away whilst the land is bare. If too short, there may not be sufficient time for tillage and weathering to enable a good seed-bed to be prepared, and the following crop has to be planted either in an unfavourable seed-bed or too late. Thus wheat planted in November can be conveniently taken after potatoes harvested in September or October, but it cannot be advantageously taken after roots folded in November because December is not a favourable month for planting wheat. Similarly it would be bad policy to grow turnips planted in May or June after potatoes harvested in October because of the waste of time and of plant food during the interval.

The growth of, and the tillage for, some crops leave the land in a suitable condition for the growth of other crops. The deep cultivation generally given to all root crops leaves the subsoil mellow yet firm for the subsequent growth of corn crops. Clover and other leguminous crops enrich the soil with nitrogen which provides plant food for subsequent crops, thus wheat can be advantageously grown after clover or beans. The fibrous roots left in the land after the growth of a ley consisting of mixed grasses and clover provide, when ploughed up, an open texture which is very favourable for the growth of potato roots, which do not have great penetrative power.

5. **The Degree of Specialisation.** It may be reasoned that a simple system enables a farm to intensify production from two or three enterprises and therefore to reduce unit cost of production more easily than a traditional mixed farm with half-a-dozen enterprises. However, prices may fluctuate considerably and seasonal effects on crops can be critical. The present trend is towards simplicity.

6. **The Control of Weeds.** Different crops have different habits and are planted and managed in different ways. Some crops such as wheat are planted in autumn, others such as barley are more frequently planted in early spring, whereas the root crops are generally planted in late spring or early summer. Each of these seasons of planting is favourable to the growth of some weeds and prejudicial to the growth of others.

Some crops, such as the cereals, are generally planted in narrow rows so that their foliage may cover the surface quickly and thus tend to crowd out annual weeds. Other crops, such as beans or turnips, are planted in wide rows so that intercultivation of the crop for the purpose of killing weeds may be carried out whilst the crop is young. These different conditions favour or prejudice different weeds. Some crops have a dense foliage which tends to shade the ground and others have a much more open foliage amongst which weeds grow freely. Barley is illustrative of such open foliage and is liable to contain many annual weeds. Oats make a much denser foliage and tend to smother weeds. A crop of marrow stem kale with its broad horizontal leaves forms a perfect canopy of foliage when well grown, and completely smothers small weeds. A mixed crop of beans, oats and tares similarly forms a dense smothering canopy.

Some crops hold the land for a longer or shorter time than others. These different conditions also favour some weeds and prejudice others. A wheat crop, growing from October to August, favours the growth of perennial weeds such as couch and thistles much more than a root crop planted in April or May and harvested in October. A long ley, during which the land is uncultivated for three or four years, is very disadvantageous to the growth of annual weeds but may lead to the spread of perennial weeds. On the other hand, the taking of two crops during the year with the additional cultivations which are entailed may, if the cultivations are well executed, help to eradicate both annual and perennial weeds.

In addition to these general considerations certain crops are introduced into the sequence of cropping with the special purpose of enabling weeds to be killed, or a bare or bastard fallow may be taken. The crops specially suited to the killing of weeds are the root crops, including turnips, swedes and other Brassica crops, as well as mangels and potatoes. Such crops facilitate the killing of weeds in three ways : they are generally planted late in spring or early in summer, so that there is a long interval of time after the previous corn crop, which gives time for cleaning operations either after harvest or in the spring before planting ; they are planted in wide rows so that both horse and hand hoeing for the destruction of weeds can be easily carried out ; they produce horizontal foliage, which, when the plants are established, shades the ground and checks the growth of weeds. Methods of controlling weeds by the use of chemical substances are described later in this chapter.

7. The Control of Plant Diseases and Pests. Diseases and pests are likely to accumulate in land continuously cropped with the same crop. Thus land is said to become "clover-sick," owing to the accumulation in the soil of one or more of several disease-producing organisms, when cropped too frequently with red clover. Turnips and other Brassica crops in the same way are likely to fail with club root, and potatoes to suffer from wart disease and eelworm if grown too frequently. Some crops, for example, barley and mangels, can be grown more frequently and yet continue to yield satisfactory crops. But with wheat, continuous cropping may lead to the accumulation in the ground of Take-all and white-heads (Ophiobolus) and other diseases, and the practice is, therefore, undesirable.

If an interval of time is allowed to elapse between the taking of two similar crops, the diseases and pests find no host plant and die out or migrate. The interval of time necessary to complete the process must, of course, depend upon the life cycle of the disease or pest, and this and other points are discussed in Chapters XIII and XIV.

THE NORFOLK FOUR-COURSE SYSTEM

From the middle of the eighteenth century until the beginning of the twentieth, this system formed the basis of a very large portion of English farming, and for the conditions prevailing during the larger part of this period was a wellnigh perfect system, especially in the drier districts.

The rotation in its original form was :

Roots—Barley—Seeds—Wheat.

The roots consisted first of all of turnips and swedes, but later on mangels, and later still kale, came to occupy part of the root break. The seeds were principally red clover, with or without rye grass, but trefoil, sainfoin, peas or beans could be substituted to widen the interval between successive crops of red clover. Where necessary, oats displaced some of the barley. The folding of sheep on arable crops and the winter feeding of bullocks in yards were essential parts of the system of farming.

At a time when artificial manures were non-existent or but little understood the system provided for the maintenance of fertility at a reasonable standard, so that the owner was insured against depreciation and the occupier was assured of good crops in the future. It provided continuous employment of labour throughout the year : the autumn was employed in harvesting some of the roots, in preparing and planting wheat, in ditching and hedging. The winter was employed in threshing corn, in feeding stock in the yards and folding sheep, in ploughing for roots and for barley. The spring was employed in completing the ploughing, in drilling spring corn and clover seeds, in cleaning the root land, and in spring-tillage of corn crops. The summer was occupied in drilling and hoeing root crops, in the hay harvest and the corn harvest. With one-fourth of the land devoted to roots, this system required a relatively large staff of labour, but during this period farm wages were very low so that this drawback was not very serious. The system provided two cash crops, namely, the wheat and the barley, and at the same time an abundance of food for livestock, namely, the roots and the clover hay as well as the cereal straw for litter, so that ample farm-yard manure could be produced to maintain fertility.

The system was specially suitable to light land farming in dry districts where the trampling of the sheep on the fold caused no detriment to the soil texture and where the sheep manure, provided the folding was properly controlled, improved not only the manurial but also the textural condition of the soil.

Where the system was applied to heavy land, sheep-folding in winter and early spring was liable to injure the texture and so prejudice the growth of the barley. In this case the roots needed to be folded early or carted from the land for consumption in the yards. On the heaviest types of clay land the root crop was eliminated and its place taken by a bare fallow.

In wet districts of the north and west, which are less favourable to barley, an oat crop was taken in its place. If potatoes were to be grown they could be planted in place of some of the roots.

MODIFICATIONS OF THE FOUR-COURSE SYSTEM

The four-course rotation broke down on economic grounds. A world depression, coupled with imported grain from the American prairies, and frozen and chilled meat from abroad, undermined the home market. The period of prosperous " high farming " ended abruptly and much land in the arable areas " tumbled down to grass ". The system was modified to meet the changing needs of agriculture and emphasis shifted to the more perishable commodities, milk, eggs, fresh meat, potatoes and vegetables. By the end of the 1914–18 War the Norfolk four-course rotation, in its original state, had ceased to exist. Most modern cropping sequences are, however, seen to be modifications of the old Norfolk system.

The Repeal of the Corn Production Act in 1921 resulted in a severe agricultural depression. The introduction of the sugar beet crop, and the sugar beet subsidy first granted in 1923, were undoubtedly a vital stabilising factor which buffered especially the East Anglian farmer against the worst effects of the depression. Some farmers changed their farming system radically, but others incorporated this profitable crop into the structure of the Norfolk system.

Four-Course Rotations. The simplest modification to meet modern economic conditions is by replacing all or part of the fodder roots by direct, high value, cash crops—sugar beet and potatoes :

Sugar Beet—Barley—One Year Ley—Wheat.

Five-Course Arable Rotations. The proportion of cash crops is raised still more by including both sugar beet and potatoes to give the following widely practised sequence :

Sugar Beet—Barley—One Year Ley—Potatoes—Wheat.

Another method of increasing the saleable crops is to extend the cropping sequence to include three cereal crops, thus:

Roots—Barley—One Year Ley—Wheat—Barley (or Oats).

This five-course system increases the acreage of cereals from one-half to three-fifths of the cultivated area and consequently increases the amount of saleable corn. At the same time the area of roots is reduced from one-fourth to one-fifth, so that a saving of labour can be effected on this crop. This means that a smaller proportion of the land is cleared each year and weeds may accumulate. This difficulty may be overcome by stubble cleaning and by the use of chemical weed-killers.

The recent introduction of efficient forage harvesting and handling machinery is likely to result in the more widespread use of high-yielding forage crops. Maize and other cereal crops grown for silage and kale may replace fodder roots and one-year leys in intensive arable cropping sequences, and on heavy land upon which it is difficult to fold stock, and where traditionally most of the roots are carted.

Winter-planted crops such as wheat and winter oats can be grown to better advantage than spring crops on heavy land, and roots are less suitable.

Six-Course Rotations. In districts and conditions peculiarly favourable to the growth of cereals, the Norfolk system may be extended to a six-course system by the introduction of corn crops in both places in the sequence as previously discussed :

Roots or Fallow—Barley—Barley—Seeds or Beans—Wheat—Oats.

In this case roots are reduced to one-sixth of the area so that the labour requirements on these is much reduced, and the cereal area increased to two-thirds. The liability to weed accumulation is further increased and must be dealt with by efficient stubble cleaning after harvest and by chemical weed-killers. In times when the only source of cultivating power was that provided by horse labour this concentration of work might have been difficult of accomplishment, but, with tractor-power available, cultivations can be so rapidly executed that this difficulty need not now arise. In cases where this rotation is applied to heavy land the roots may be in part or in whole substituted for by a bare or bastard fallow, the latter consisting either of trefoil or other crop cut for hay or silage, or folded before being fallowed in July.

When cereal prices are high this system provides good returns under suitable conditions, but is relatively unprofitable when cereal prices are low.

A six-course system commonly adopted for potato growing in some southern districts runs as follows :

Roots—Barley—Seeds—Potatoes—Wheat—Oats.

In this case potatoes are taken after clover, which is a very favourable arrangement, partly because of the accumulation of nitrogen by the clover, but especially because the fibrous roots and stubble of the clover produce humus and a good soil texture in which the potatoes revel. It also provides a longer period of growth for the clover, and mixed grasses if any, in autumn than in the case where the layer must be ploughed up for wheat sowing in autumn. The rotation provides for two cleaning crops, roots and potatoes, in six years so that the land can be easily kept clean, and the potatoes can be cashed to advantage, as well as the three cereal crops.

Another six-course system suitable for the growing of potatoes is that called the East Lothian system, which runs as follows :

Roots—Barley—Seeds—Oats—Potatoes—Wheat.

In the district of East Lothia and other parts of Scotland to which it is applied, conditions are often more favourable to the growth of oats than of other cereals, and the crop can commonly be marketed to advantage for oatmeal. This crop is therefore taken after the seeds, where it benefits from the accumulated fertility of the clover roots. As the oats are sown in the spring a longer grazing period is available on the clover stubble. In other respects its advantages are similar to the previously described six-course system.

The cropping sequences discussed above are typical of most arable farming districts in Britain, but some notable exceptions must be mentioned. The relative simplicity of growing and harvesting cereals, and their relative profitability, has resulted in repeated and continuous cereal cropping in some districts. In high-fertility areas successive wheat crops, and in lower fertility chalk land areas barley crops, are often successfully grown. With wheat such practice involves added risk of the build-up of certain diseases such as Take-all and Eyespot, although the use of resistant varieties of winter wheat, and the extended use of the less susceptible, improved spring wheats counters this danger to some extent. Barley is less susceptible to these risks. Fertility is maintained by the liberal use of chemical fertilisers and by ploughing-in the larger crop residues obtained. Meanwhile interest in oats has declined due to lower average yields and added harvesting problems compared with wheat and barley.

Silt and Fenland Rotations. These soils are deep and rich and the land is very valuable. Consequently high value crops predominate in the rotation which takes the form :

Potatoes—Sugar Beet—Wheat

or

Sugar Beet—Potatoes—Wheat.

These crops are frequently accompanied by market gardening crops such as bulbs, celery, peas, brassicas and root crops for seed.

EXTENDING THE SEEDS LEY

In the Norfolk and similar systems the clover and other " seeds " crops have been described as one-year leys, growing for one year only. These systems have proved specially suitable to the drier districts of eastern and southern England in times when cereal prices were remunerative, because in these districts the second growth of red clover in the first year can often be profitably harvested and cashed as seed, and because weeds and wireworms tend to accumulate in second and third year seeds to the serious disadvantage of subsequent crops.

In moister districts the leys are commonly kept down for two, three or more years. The first extension gives a six-course arable-with-grass rotation :

Potatoes—Wheat—Sugar Beet—Cereal—Two Year Ley.

The proportion of cash crops remains high and provision is made for livestock to consume the grass and arable by-products. Expressed in this way it represents a further extension to the Norfolk system.

ALTERNATE HUSBANDRY

A further extension of the " seed " course to three or more years, or the inclusion of a long ley, leads to a practice more graphically described by the term " alternate husbandry ".

In alternate husbandry the and, having been cropped for some years, is laid down to ley or temporary pasture for a number of years, after which it is again broken up and cropped. Whilst the land is under ley many advantages are obtained. The land becomes filled with fibrous roots of grasses, clovers and other plants which, together with the surface vegetation, greatly help the texture of land when next the ley is broken up. The fertility of land, measured in terms of humus and nitrogen, can be rapidly increased in this way, and in minerals also if lime, phosphates and potash are added by way of top-dressings.

Under proper management the increase of fertility is largely associated with the presence of white clover. The annual cost of management is greatly reduced after the initial seeding, whether in the preceding corn crop or by direct seeding on bare ground, since little further cultivation is required. The cost of harvesting is relatively small in the case of silage and hay-making, and much less when the ley is grazed.

During the period of temporary ley, production of herbage under good management is generally very great, and often on inferior land much greater than that of permanent grass grown upon similar land. This is due mainly to the establishment of more prolific species of plants under more favourable environmental conditions than those occurring in the old pasture. Coincident with this is the fact that stock thrive better upon new leys than upon old pasture, not only because of the more abundant herbage but also because the new temporary ley is relatively free from pests and diseases. A further advantage is that the system permits better weed control since the same weeds are unlikely to thrive both on grassland and arable land.

When the ley is broken up and recropped the fertility stored up by the nodules of the leguminous plants, by the organic residues of the grass and clover roots and stems, by the top-dressings applied to the pasture and by the droppings of the animals grazed on the pastures, is utilised for the production of crops. This accumulated fertility is mainly in an organic condition which, under arable conditions, becomes progressively available for plant growth. In this way the fertility stored during the ley period can be utilised in the production of cash crops, and when this fertility is partially exhausted the land may be again laid down to ley and the process repeated. It will be noticed that under this system fertility is maintained without the use of farmyard manure, the carting of which, especially to outlying fields, involves the use of much manual and horse labour. Any farmyard manure produced on the farm can, if desired, be used upon fields near the buildings or devoted to special cash-producing crops, such as fruit and vegetables.

There are, however, some drawbacks to alternate husbandry. The capital required for fencing and water supply may be high, although at present grants are available towards such costs. Good seeds mixtures are expensive, while the purchase of stock to graze the leys demands still more outlay. New leys suffer much more from " poaching " by livestock in wet seasons and in winter than permanent grass, a disadvantage on some stock farms.

Alternate husbandry is basically a higher cost system, but it has the great advantage of flexibility to meet changing conditions in competitive farming. When arable farming is relatively profitable leys can be ploughed out earlier ; where livestock farming is relatively more profitable leys can be left down longer. Since the introduction of the ploughing grant in 1939, the State has encouraged the system and currently grants of seven pounds per acre are available to encourage maintenance of the tillage area and regular ploughing-up of leys.

On heavy land, and land unsuited to root crops, cereal crops may alternate with grassland as follows :

Wheat—Wheat—Barley—Long Ley.

It may be convenient on a mixed dairy and arable farm to practise two sequences of cropping ; an inner sequence near the buildings consisting of fodder crops such as Italian ryegrass, cereals, maize and kale ; and an outer sequence made up of cash crops and long leys.

This system of ley farming or alternate husbandry has been practised in the moister districts of England and especially in Scotland for many years, and has received special attention since the discovery of the outstanding value of wild white clover as a nitrogen-collecting plant, and the use of basic slag and close-grazing in stimulating its growth. It has now spread to most parts of the country, due partly to the stimulus of war-time farming, and partly to the development of improved techniques for establishing and managing leys. These techniques are discussed in Chapter XI.

CATCH CROPPING

Catch cropping is not a system of farming in itself, but consists in the snatching of an extra crop between two of the main crops of a rotation. An example of a catch crop is the broadcasting of Italian ryegrass or rape on a scarified corn stubble in autumn to provide keep during early spring, after which the land is prepared for a late sown crop. Similarly, winter rye or a mixture of winter rye and Italian ryegrass sown in early autumn are frequently used to supply " early bite " on dairy farms. It is a common practice in some districts where early potatoes are grown to plant a catch crop of Italian rye grass immediately the crop is lifted : the forage can be grazed off or ploughed in as green manure. Mustard is frequently planted as a catch crop after a bare fallow, to be ploughed in during the preparation of the ground for autumn wheat. The mixing of small quantities of rye-grass and trefoil with spring sown oats or barley is also catch cropping, for after the removal of the cereal the forage plants can either be grazed or allowed to grow unchecked before being turned under during cultivations prior to the planting of the next major crop in the rotation.

Opportunities for catch cropping on heavy land are limited, and it is essentially a light land technique for intensifying land use and raising the grass output. The chief advantages are : provision of stock feed at difficult times of the year ; replacement of main crops that have failed ; conservation of nutrients, especially nitrates ; checking of weeds ; and additions of crop residues when ploughed in. The main disadvantages of catch cropping are possible detrimental effects on the yield of the following main crop by the removal of nutrients and water from the soil, and the temptation to leave a successful crop down too long, with subsequent delay in seed-bed preparation.

IRRIGATION

Irrigation is the artificial application of water to the soil to ensure an adequate supply of moisture to meet crop needs. Under natural conditions a small part of the crop's requirements is available from the moisture reserves stored in the soil from rain falling on the land before the crop is sown ; the remainder, and by far the greater portion, is supplied by rain falling directly on the soil during the growing period. Thus the amount of rainfall and its distribution during the growing season largely controls the availability of soil moisture and considerably influences crop yields. Over large areas of this country the amount of rainfall during the growing period is generally inadequate, because its distribution is poor in relation to crop needs: lack of soil moisture frequently reduces crop yields. In these conditions irrigation is used to supplement natural rain as and when necessary to provide adequate moisture for the crop. Used correctly, irrigation will pay handsomely over a wide range of conditions.

The amount of water that is available to the plant from the reserves of moisture in the soil depends on two things : the amount of water that is available per unit depth of soil, and the depth of soil from which the particular plant can extract moisture. It is usual to refer to the amount of water available per unit depth in terms of *inches of water per foot of soil.* Similarly, the amounts of irrigation water applied to, and the quantities of moisture used from, a soil are also referred to in terms of *inches depth*, 1 inch of water being 1 inch depth over the prescribed area. Generally, light textured soils have smaller moisture reserves than heavy soils : a very approximate guide to the water reserves of various soils is given below.

APPROXIMATE MOISTURE RESERVES OF SOILS

Soil Texture.	*Inches per foot of soil.*
Coarse Sand	¾-1
Sandy Loam	1 -1¼
Medium Loam	1¼-1¾
Clay Loam	1¾-2¼

The depth of soil from which a plant can draw water is largely dependent on the type of crop, provided normal root development is not restricted by soil or other conditions. For irrigated farm crops the rooting depths are given in the next table. The depths given are not the maximum rooting depths of the crops, nor the extreme depths from which moisture extraction occurs, but they indicate the depth of soil to be considered for irrigation purposes.

"ROOTING DEPTHS" OF CROPS UNDER IRRIGATION

9-15 in.	*15-18 in.*	*18-24 in.*
Potatoes	Peas	Sugar Beet
Short grass	Beans	Long Grass
	Mangels	Lucerne
	Brassicas	

From the information given in the above tables it is possible to estimate the total soil moisture reserves available to the crop growing on a particular soil. Thus, for sugar beet growing on a sandy loam the total soil moisture reserves will be 2 in. ; the reserves are 1 in. per foot of soil, the depth of rooting being 2 ft.

The amount of water and the rate at which it is used by a crop are determined by the weather conditions, so long as there is a supply of available moisture in the soil, and are independent of the crop itself providing the crop gives reasonable ground cover. On average, in this country water will be used at the rate of 1 in. every 14 days in April and September, 1 in. every 10 days in May and August and 1 in. every 8 days in June and July. These figures vary little year by year except during periods when there is an unusual excess or lack of sunshine. If rainfall is insufficient to provide water in the above quantities, the moisture reserves of a cropped soil will be depleted and exhausted after several days of dry weather. Irrigation should be applied before the soil reserves have been depleted to the point where plant growth is checked.

The amount of available water per unit depth is determined by measuring the volume of water held by the soil at two reference points, *field capacity* and the *permanent wilting percentage*.

Field Capacity. On many well-drained soils the moisture content of the soil falls to a fairly definite value after rain or irrigation has ceased, provided evaporation is prevented. In this condition the soil is holding the maximum quantity of water against free drainage, and the soil moisture reserves are at the maximum. In this state the soil is referred to as being at field capacity. Any additional water applied at this stage will not be retained by the soil and will be lost through drainage.

Readily Available Moisture. A plant growing in the soil removes water, until the water remaining in the soil is held so firmly that the plant is unable to obtain sufficient water to meet its needs and the plant wilts. A soil in this condition is at the permanent wilting percentage, and the moisture reserves of the soil available for plant growth are exhausted. The volume of water in the soil held between these two reference points is known as the *readily available moisture*.

It is now generally accepted that as a soil dries from field capacity towards the permanent wilting percentage there is a falling off of the growth rate and a reduction in marketable yield of a crop. The amount of available water that can be used from the soil without seriously affecting the marketable yield depends on a large number of factors and it is not possible to use the same standards for the irrigation of all crops. Recommendations based on existing experimental data and practical experience are given later.

Soil Moisture Deficit. As the timing of the irrigation and the amounts of irrigation water to apply must be related to the amount of water used from the soil, it is necessary to estimate this. In practice a reasonable estimate can be obtained by comparing the quantities of rainfall or irrigation for the period in question with the water-use figures for the same period. When the water-use exceeds the amounts of rainfall or irrigation, moisture will have been used from the soil and a soil moisture deficit will exist. The *soil moisture deficit* is the amount of water required to restore the soil to field capacity. The size of this deficit and the crop conditions will determine whether or not irrigation is necessary. More details and the figures of water-use for specific areas are obtainable from the Ministry of Agriculture's Technical Bulletin No. 4 " The Calculation of Irrigation Need ".

Irrigation Practice. For most farm crops sufficient water should be applied at each irrigation to restore the major portion of the root-zone to field capacity—in other words to satisfy the soil moisture deficit completely. On heavy soils it may be advisable to leave ½ in. deficit to accommodate any immediate rainfall. More water than the quantity required to restore the major portion of the root-zone to field capacity should never be applied.

It is usually unsound to irrigate for the purpose of hastening germination of seeds. If the seed-bed is likely to be dry the soil should be irrigated during seed-bed preparations : irrigation should not be carried out immediately after sowing, nor in the young seedling stage of the crop. During dry weather, late sown crops of kale, peas, etc., often benefit from water before sowing, and an application of from 1½–3 in. of water should be applied before the land is ploughed or before final seed-bed preparations are made. The smaller application is usually sufficient for light soils, but 3 in. may be required on heavier soils after a long dry period.

Early Potatoes. Irrigation should be applied when 50 per cent of the total soil moisture reserves have been used, the water used from the soil being calculated from the time when 80 per cent of the plants have emerged and have produced small bushy plants 4–5 in. high, each having 3 or 4 leaves. Irrigation should stop some 5 days before the crop is to be lifted to allow the soil to dry out and the crop to benefit from the water applied. On light soils it may be more economic to withhold irrigation until 1 in. is required than to apply smaller quantities more frequently. Where water or equipment is restricted, a single application of 1 in. (if needed) some 14 days before lifting will be beneficial.

Maincrop Potatoes. Irrigation should not be considered until the tubers have formed and are about the size of small marbles. Water should then be applied when 50 per cent of the soil moisture reserves have been used, and continued until leaf drop due to blight or maturity prevents any further yield increase. Again, it may be more economic to delay irrigation until 1 in. is required than to give more frequent light applications. On farms where there are limited irrigation facilities, the most critical period for water shortage is early July. Infrequent and irregular irrigations may reduce the quality of the crop because they may induce secondary growth.

Sugar Beet. The use of irrigation should be considered from shortly after singling, when the plants are just meeting in the row, until about the middle to the end of August. Irrigation is required when 50 per cent of the soil moisture reserves have been used up during this period. July and early August appear to be the critical periods, if irrigation facilities do not permit continuous irrigation. Irrigation after the end of August may reduce the sugar content of the crop, which is not fully compensated for by the corresponding increased root weights.

Cereals. On light soils and in a dry spring, a single application of 1–1½ in. is frequently well worth while. Cereals are most responsive to irrigation when they are starting to run to ear.

Peas. Normally, irrigation is not necessary before flowering except in very dry summers, and water should only be applied from flowering onwards when 60 per cent of the soil moisture has been used. At the first irrigation the aim should be to restore to field capacity or give 2 in. of water, whichever is the less ; but smaller quantities are beneficial. Late-sown crops of peas are likely to respond to seed-bed watering.

Grassland. Maximum production is obtained if the soil is maintained as close to field capacity as possible. In practice it is most convenient on grazing fields to restore the soil to field capacity when 1–1½ in. have been used, and when 1½–2 in. have been used from hay and silage swards, regardless of soil type. A typical schedule for a grazing field would be to graze, top dress with fertiliser and irrigate, to give a second irrigation in 7 to 10 days if necessary, and graze again in a further 8 to 10 days.

Kale and Mangels. No irrigation is necessary before there is reasonable ground cover, and then irrigation should start when 60–70 per cent of the soil water reserves have been used.

Haphazard watering may give rise to some benefits but is usually wasteful of water and equipment, the best results being obtained from controlled irrigation. Benefits other than yield increase are frequently obtained from controlled irrigation, because the quality of the produce is often improved and the time the crop reaches the marketable stage can sometimes be influenced favourably.

WEED CONTROL BY CHEMICAL METHODS

The primary purpose of weed control is to prevent weeds competing with a crop for nutrients, light and water and so reducing the yield. Weed control often benefits the farmer in other ways, for it brings about easier singling in root crops, easier harvesting of cereal crops and so on.

For very many years weeds have been kept under control by good rotations, ploughing, cultivations, hoeing and hand pulling and these methods are still of value today. The control of weeds by chemicals is of recent origin. At the beginning of this century a limited use was made of calcium cyanamide and finely powdered kainit, and also 3–4 per cent solutions of copper sulphate in water, to destroy charlock and wild radish growing in cereal crops. The broad, hairy, more or less horizontally held leaves of the weed retained the dusts or liquids, which were held to a much less degree by the narrow, vertical leaves of the cereal. In the 1920's, sulphuric acid at concentrations of 7–10 gallons of B.O.V. (brown oil of vitriol) in 100 gallons of spray per acre was used. Later it was discovered that certain types of mineral oil, such as the vaporising oil used as tractor fuel, have little effect upon the growth of umbelliferous plants, including carrots, parsnips and parsley, but are toxic to many non-umbelliferous annual weeds. In 1939 compounds of dinitro-ortho-cresol (DNOC) began to be widely used. Since 1939, when the synthetic growth regulating substances were discovered, selective weed control has developed at a tremendous pace.

Selective Weed Control. A selective weed killer, or selective herbicide, is a substance which checks or destroys weeds without seriously harming the crop in which the weeds are growing. The word herbicide, meaning plant killer, is used partly to avoid the suggestion that these substances will kill only weeds : crop plants may be killed just as readily if the chemical is used on a crop or in a way for which it is not recommended. To control weeds effectively it is not always necessary to kill them ; sometimes sprayed weeds do not die but remain stunted and fail to set seed, which is quite as beneficial to the farmer.

The selectivity of a herbicide is only a matter of degree : there is no chemical which will have absolutely no effect on the crop and yet will kill all weeds. Most herbicides check the crop very slightly, and some weeds, even of those species regarded as susceptible, usually manage to survive. Each herbicide has a range of weeds on which it has varying degrees of effectiveness and some which are quite unaffected by it and are termed " resistant ".

The selectivity of any herbicide depends on the amount applied : a high rate will often kill both crop and weeds. Selectivity is also very dependent on the stage of growth both of crop and of weeds. For each herbicide and crop the stage of growth at which it is safe to spray must be carefully defined : at other stages there may be crop damage. As weeds become older they become more resistant to herbicides so that satisfactory control is often dependent on spraying as soon as the crop reaches a safe stage.

Selectivity may also be affected by other factors, such as the volume of spray applied per acre, air temperature at time of spraying, and cultivations before or after spraying.

Herbicides can be classified according to their mode of action, as shown below :

Contact herbicides.	*Translocated Herbicides.*	*Residual Herbicides.*
Sulphuric acid	MCPA and related chlorophenoxy compounds	TCA
DNOC	Dalapon	Simazine
Dinoseb	Aminotriazole	Monuron (CMU)
Mineral oils	Sodium chlorate	Chlorpropham (CIPC)
Sodium monochloroacetate	Barban	" Avadex "
Diquat		

Contact herbicides have a rapid scorching action on those plant tissues with which they are brought into contact. They are not moved about inside the plant to affect other parts untouched by the spray. If the scorching is sufficiently extensive the plant will be very severely checked or it may die, but it will recover from a slight scorching. Therefore good coverage of the plant by the spray is very important with contact herbicides and a high volume of spray (60–100 gallons) per acre is generally applied. Contact herbicides will often kill the shoot systems of perennial plants but regrowth takes place from the unaffected root system.

Translocated herbicides have normally no scorching (or contact) effect but are absorbed by the leaves of the plant and moved about within it, causing a slow but profound disturbance of the normal processes of growth and eventual death of susceptible plants. In their effect on growth many of these translocated herbicides resemble auxins, the natural growth regulating substances present in all plants, and they are sometimes described as " growth regulators ". This applies to all the MCPA group listed above, which produce characteristic twisting of the stems and leaf stalks and general severe distortion of the normal growth habit. Because of their movement within the plant these herbicides can be carried down to the root system of perennial plants and can effectively control many, though not all, perennial species. In contrast to the contact herbicides, complete coverage of the plant by the spray is not necessary and low volume sprays are generally used.

Residual herbicides are applied to the soil and are taken up by plant roots. They persist in the soil for some weeks and are intended to kill weeds either when the seeds are germinating or in the very young seedling stage. They are normally used for horticultural and root crops with the pre-emergence technique described below.

The most familiar type of treatment is to dilute the chemical with water and spray when the seedlings of both crop and weeds have emerged from the soil. This is known as " post-emergence " (i.e. after the emergence of the crop) and is the most common way of using contact and translocated herbicides.

Residual herbicides are usually applied soon after the seed of the crop has been sown but before the crop seedlings have appeared above the ground, i.e. the " pre-emergence " technique, before the emergence of the crop. Young weed seedlings and germinating weeds are killed and the soil kept clear for some weeks by the residual activity of the herbicide. In some uses the selectivity depends on the inherent tolerance of the crop to the herbicide ; in others the crop may be liable to damage by the chemical but is protected by being sown deep enough to escape the full effect. The results with pre-emergence treatment are very much influenced by soil type, rainfall after application and temperature ; the method calls for a good deal of skill and is not at present widely used. Contact and translocated herbicides may also be used pre-emergence, e.g. sulphuric acid on the onion crop.

Non-selective or Total Weed Control. It may be necessary to kill weeds on land which is not cropped, such as paths and around yards and buildings or on waste land which has become overgrown. Sometimes weeds can be killed in arable land in between crops, such as couch or twitch or bindweed in cereal stubbles. Here the herbicide need not be selective as between crop and weed, and a chemical can be used such as Dalapon for couch or twitch, which would be severely damaging to the corn.

Often, in addition to destroying existing vegetation, it is desired to keep the land free from weeds for as long as possible (soil sterilisation). Here a very persistent residual herbicide is needed—a suitable application of monuron will keep land free from all vegetation for a year or more.

The chemicals used for these purposes may be the same chemicals which can be used selectively on crops, simazine for example, but they would be applied at considerably higher rates. Or they may be chemicals which have no selective use—Dalapon, sodium chlorate or borax compounds.

Herbicides are sometimes used where no weed problem arises.

The burning-off of potato haulm is one example, using sulphuric acid or one of the newer chemicals such as Diquat. Clover seed crops carrying a lot of leaf can usually only be direct combined by first burning off the leaf with similar chemicals, a technique known as pre-harvest desiccation. Recently a method has been devised of re-seeding grassland without ploughing by first killing the existing grass sward with a herbicide such as Dalapon and then sowing the seed after light surface cultivations or rotavating.

The chemical nature of herbicides. Some herbicides are simple inorganic chemicals, e.g. sulphuric acid, sodium chlorate, but most are more or less complicated organic chemicals synthesised especially for this purpose.

It is not possible to list even the main groups of the large and yearly increasing number of organic chemicals but the most important to the farmer are the chlorophenoxy compounds, all related chemically to MCPA, classified as follows :

Chlorophenoxy acetic acids : MCPA ; 2,4-D ; 2,4,5-T
4-CPA.
Chlorophenoxy proprionic acids : Mecoprop (CMPP)
2,4 DP
2,4,5 TP
Chlorophenoxy butyric acids : MCPB ; 2,4-DB

Where the basic chemical is an acid, as in MCPA, the commercial product may be applied as one of its compounds referred to as " salts " (commonly sodium, potassium, ammonium or amine) which are water soluble : or as an ester, a compound dissolved in oil with an emulsifier so that it forms an emulsion when diluted with water. In all these compounds it is the parent acid which is the active agent, and rates of application are therefore quoted in terms of the amount of acid to be applied, e.g. " 2 lb. acid equivalent per acre ". The concentrations of commercial products are stated in the same way, e.g. " contains 4 lb. acid equivalent per gallon ". The way in which the parent material is made up commercially is known as its *formulation* and the method of formulation can modify its activity and other properties.

Detailed information about herbicides and their influence upon crop plants and weeds is given in Appendix VI.

Chapter IX

THE CULTIVATION OF CEREAL AND PULSE CROPS

THE CEREALS

THE cereals wheat, barley, oats and rye are grasses with enormously swollen grains used extensively for human consumption and for feeding to farm livestock. Although they have been cultivated for a very long time and are familiar to most people, yet occasions do arise when it is not easy to distinguish between the cereals, especially if the ear is not visible.

The Recognition of Cereals. By paying special attention to certain details of structure it is possible to identify the cereals with certainty at any stage of growth.

1. Seed. As in all the Gramineæ the grain of the cereals is a one-seeded fruit, or caryopsis, in which the bulk of the grain is occupied by starchy food reserves (endosperm) ; at one end of the grain is the embryo, or germ. In wheat and rye the grain is naked, but in barley and oats the grain is wrapped round by two chaffy leaves called the paleæ, or pales. The appearance of the four grains is shown in Fig. 28.

2. Seedling. When germination takes place in wheat and rye both the plumule (or shoot) and the young radicles burst forth from the embryo end of the grain as shown in Fig. 28A. But in barley and oats the plumule is at first hidden by the pales, and it is unable to burst its way out until it has grown at least half as long as the grain. Consequently, it appears that the rootlets and plumule of barley and oats arise at opposite ends of the seed, though this is not really the case.

In the very young seedling stages it is possible to identify cereals by digging up the plants and examining the sprouted grains.

3. Established Plant. As the plants get older, however, the grain rots away and it is no longer possible to use its characteristics as a means of recognition. Attention must then be devoted to the appearance of the leaf. As in all grasses, the cereal leaf is in two parts. There is a portion called the sheath which clasps the stem between one node of the stem and the next, and there is the blade itself. Where sheath meets leaf there are, in wheat, barley and rye, extensions of the sides of the blade called auricles, or claws. In wheat the claws are of moderate size, and carry a few long, scattered hairs. In barley the claws are relatively very much longer and overlap considerably ; they are bare, or quite without hairs. In rye the claws are very tiny, but the sheath is purplish. In oats there are no claws whatsoever (Fig. 29).

4. Ear. The recognition of oats when in ear presents no difficulty, because the ear is so obviously branched, each branch or

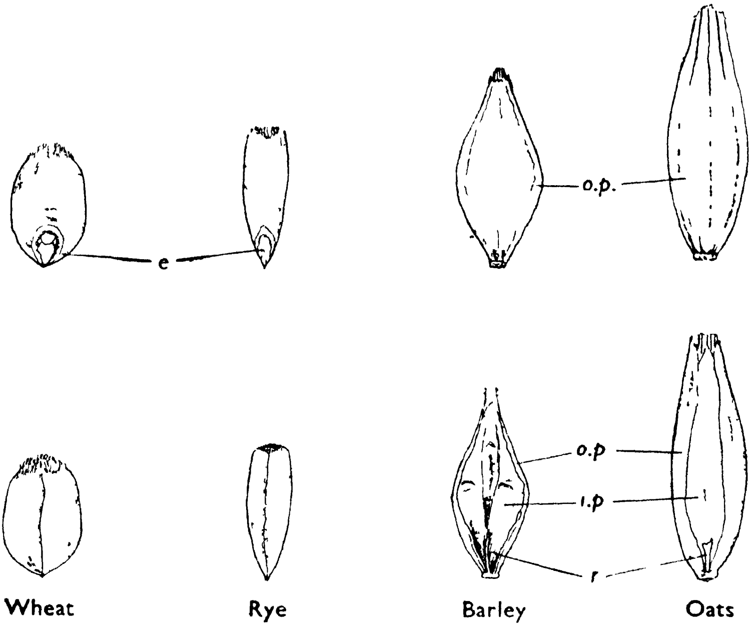


FIG. 28.—GRAINS OF THE CEREALS.
e, position of embryo *o p*, outer pale. *i p*, inner pale *r*, rachilla.

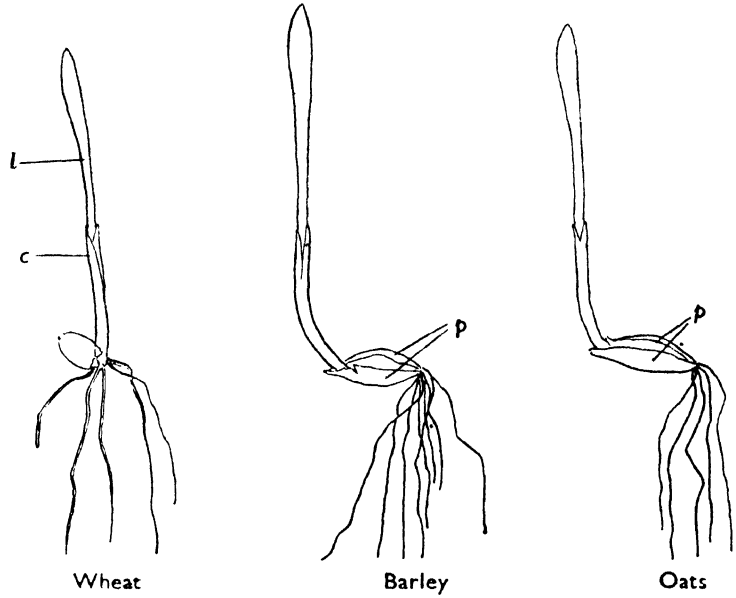


FIG. 28A.—SEEDLINGS OF THE CEREALS.
c, coleoptile or sheath. *l*, first leaf. *p*, pales.

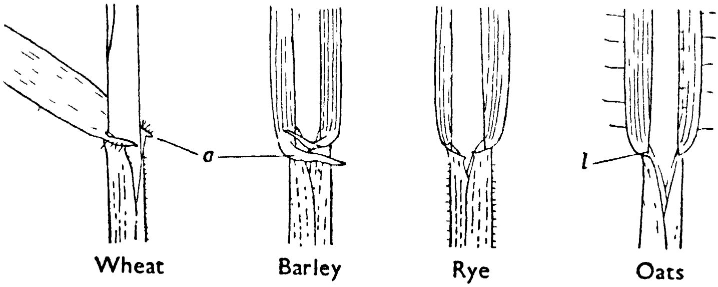


Fig. 29.—Auricles and Ligules of the Cereals.
a, auricle. *l*, ligule.

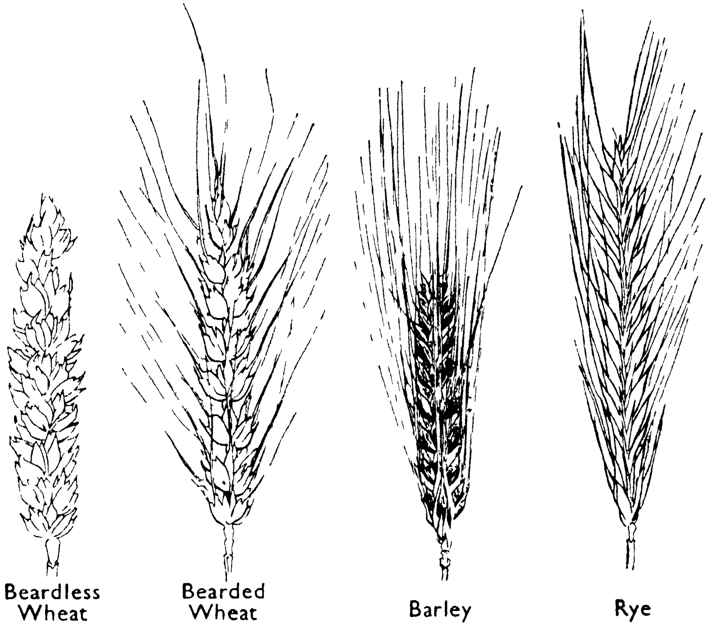


Fig. 30.—Ears of the Cereals.

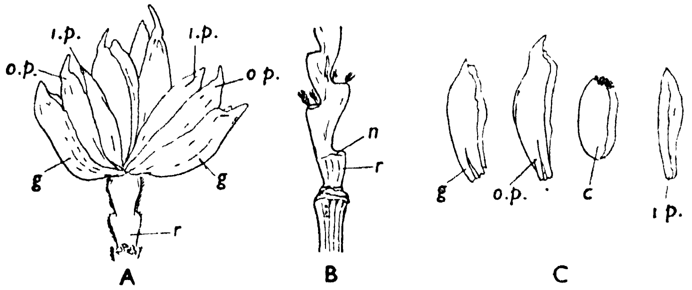


Fig. 31.—Spikelet of Wheat.
A, single spikelet. B, rachis (much enlarged). C, detail of floret and glume.
r, rachis. *g*, glume. *o.p.*, outer pale. *i.p.*, inner pale. *c*, caryopsis or grain. *n*, notch of rachis.

sub-branch terminating in a spikelet, or collection of florets. But in the other cereals the ear is unbranched, the spikelets being situated direct upon the central stalk, or rachis (Figs. 30, 33).

In wheat there is one spikelet at each notch of the rachis and the outside coverings, or glumes, of each spikelet are very broad. The coverings to the individual floret, which eventually enclose the grain, are the pales, of which the outer or dorsal pale is much the larger (Fig. 31). In almost all the wheats commonly grown in this country the outer pale ends in a point, but in certain wheats such as Rivet and April Spring Bearded, the tip of the outer pale grows out into a long, rough bristle or awn. These awned, or bearded wheats may be mistaken for barley on casual inspection (Fig. 32).

Actually the make-up of an ear of barley is quite different from that of wheat. All barleys have three spikelets at each notch of the rachis, a central spikelet lying against the flat of the rachis, and two lateral spikelets. The two glumes of each spikelet are very narrow, each with a fine awn at the tip. In six-rowed barleys (which include the so-called four-rowed barleys) each spikelet gives rise to one grain, tightly wrapped round by the pales, the outer of which bears a long awn. The awn, of course, is broken off during threshing and is not found in the seed. In two-rowed barleys only the central spikelet forms a grain, but the glumes and pales of the infertile lateral spikelets can easily be seen adhering to the rachis (Fig. 32).

Rye has the same general make-up as wheat, with a single spikelet to each notch of the rachis. But it can easily be recognised, first by the very tiny, narrow glumes, and second by the large outer pales, which taper from a broad base to a very long, rough awn. Usually there are only two grains per spikelet, whereas wheat may have from one to five grains per spikelet.

Further information concerning the structure and behaviour of the Gramineæ can be found in Chapter XI.

WHEAT

The cultivation of the so-called " bread " wheats is spread over all countries with temperate climates. These varieties belong to the species *Triticum vulgare*, which includes the bulk of the European, Canadian, American and Australian wheats.

There are many variations in the size, shape and colour of the grain of different varieties of wheat. In some the grains are long and narrow with a distinct groove or furrow on the ventral surface, in others they are short and plump ; the outer skin may be red, white, brown or pink, whilst in cross-sections the interior may be white and starchy, or steely and translucent. Varieties of good baking quality—the " strong " wheats—exhibit the steely appearance, whereas the white or mealy grains of the " weak " wheats indicate varieties of inferior quality which may yield very well but which are suitable only for feeding to livestock or for biscuit manufacture.

Apart from the characteristics of the grain already described, such factors in wheat as earliness and lateness in ripening, resistance or non-resistance to disease, adaptability to conditions of soil type and degrees of soil fertility, and the capability to withstand adverse winter weather, are of great economic importance. Yield of grain is the result of a large number of contributory causes, and it is not until they are all operative in the same direction that maximum results can be obtained. For instance, a crop of great promise may be so badly attacked by rust or mildew that the resulting grain is only half its normal weight and size, leading to a corresponding reduction in the final weight of crop. It is not uncommon to experience serious loss in yield as a result of the crop becoming lodged due to the inability of the straw to support the heavy ears until harvest time. Varieties also vary from season to season so that conclusions as to the value of any particular variety should not be reached until experience over at least three seasons has been gained.

Quality in Wheat. The large-scale buyer of wheat takes into consideration three main items before making a purchase of a particular lot of grain. These are its condition, its milling characteristics and the quality of its flour. The condition of the grain has little to do with variety, though some varieties are naturally of better appearance than others and white wheats are usually preferred to red wheats. Grain in good condition is undamaged, free from screenings, clean and dry enough to store well. For normal storage in bulk, the moisture content should not exceed 14 per cent. The farmer can influence, and is responsible for, the condition of the grain he offers for sale.

The miller naturally desires a wheat of good milling quality. A " free-milling " wheat is one in which the flour is easily and completely separated from the bran, while the flour itself is in a granular or gritty condition, in which state it can easily be screened or sieved. Milling quality is quite distinct from baking or bread-making quality. For example, the variety Pilot has good milling characteristics but its flour is of poor bread-making quality. The variety Cappelle Desprez mills poorly, but has fairly good flour quality. The spring variety Atle has both good milling and good baking qualities.

Quality in flour is usually judged from the bread-making angle. A good bread-making wheat yields a flour whose dough is elastic and which bakes into large loaves of even texture and a good shape. Such a wheat is often said to be a " strong " wheat in contrast to a " weak " wheat whose flour bakes into a smaller, denser, less-even-textured loaf. Wheats imported from Canada and U.S.A. are " strong " wheats whose capacity for making large, well-shaped loaves of good texture make them popular with bakers. In contrast, most of the wheat varieties grown in this country yield a " weak " flour, but Elite Lepeuple, Banco, Dominator and Milfast, amongst the winter varieties, and the spring varieties Atson, Svenno and Koga II, Jufy I, are all good bread-making wheats which also mill easily.

For biscuit-making, however, wheat flour should yield a dough which is not so much elastic as viscous. It so happens that most of the accepted biscuit-making wheats are of only moderate milling quality : they include Squarehead's Master 13/4, Minister, and Flamingo.

Quality for both bread-making and biscuit-making depends very much upon the nature and amount of the gluten in the grain. Gluten is a protein which can be increased to some degree by the amount of nitrogen given to the plant as a fertiliser, though nitrogen cannot alter the nature of the gluten and change a poor-quality wheat into a good-quality wheat. Nitrogen can, of course, very markedly increase the yield of grain of both autumn-sown and spring-sown wheat crops. Certain varieties, such as Hybrid 46, Cappelle Desprez and Minister, have been specially bred with very short, strong straw, capable of supporting the ears even when heavily manured with nitrogen. Yields of well over two tons of grain per acre are not uncommon with these varieties ; unfortunately, the flour quality of these very productive varieties is not high. Much effort is being made at the present time by plant breeders to combine the high yielding characteristics of these varieties with the good milling and baking characters of varieties like Holdfast and Yeoman, which are now obsolete.

Varieties. Only two species of wheat have been grown commercially in this country in recent times. These are *Triticum turgidum*, in which the normal or $2n$ number of chromosomes in the cell nucleus is 28, and *T. vulgare* in which $2n = 42$ (see page 462). The *T. turgidum* types grown were known as Rivet or Cone Wheats. An improved higher yielding variety known as Rampton Rivet was produced some years ago and was moderately popular for a time. All these *T. turgidum* wheats were late maturing and quite unsuited to the modern techniques of growing and handling the crop. They are now obsolete.

The species *T. vulgare* embraces varieties which are sown in autumn and varieties which are planted in spring. If true autumn varieties are planted after about the middle of February they yield very much less than when drilled at the proper time. If planted after the end of March they may even form no ears at all. Generally speaking, winter wheats yield more grain than spring wheat, though spring varieties like Jufy I and Koga II can yield up to two tons per acre in fertile conditions. The number of varieties offered for sale to farmers is very large, and new varieties are continually being introduced. There is no point in adopting a new variety of wheat unless it has some advantages not possessed by an existing type, and the best general guide to varieties is the list of recommended and provisionally recommended varieties published annually by the National Institute of Agricultural Botany. The current list of recommended varieties is given in Appendix V. It should be realised that the list is drawn up as a result of a comprehensive programme of variety trials carried out at a number of centres throughout the country and for a minimum of three years at each centre.

Early successes with wheat resulted from the selection of individual plants of superior character from the mixed population of types which constituted the old ‘ land race ’ varieties. Later work involved the hybridisation of two varieties and the selection of desirable types within the progeny of such crosses (see pp. 472–474). A land-mark in the hybridisation technique of breeding was the production of the two varieties, Yeoman and Little Joss, by Sir Roland Biffen at Cambridge. Yeoman was the result of a cross between the, by former standards, high yielding variety Browick and the high bread-making-quality Canadian wheat, Red Fife. It combined high yield and good baking quality in the one variety. It is of historic importance also in that it showed that baking quality, although influenced by environment, was inherited on Mendelian lines. Little Joss was the result of a cross between Squareheads Master and Ghurka and it combined in the one variety good yield with resistance to Yellow Rust (*Puccinia glumarum*) (see p. 379). It also is of importance historically in showing that disease resistance could be inherited on Mendelian lines. Although both these varieties are obsolete they have been used as parental types in many subsequent crosses.

During the last twenty-five years three main developments have taken place. The first is the great success achieved in France and Belgium in breeding for straw strength. As a result of reducing the danger of lodging, the varieties produced have permitted higher levels of fertiliser to be used—which in turn has made possible a general increase in wheat yields. Varieties like Cappelle Desprez, Professor Marchal, Minister and Elite Lepeuple are tributes to their success.

The second development has been the realisation that Yellow Rust exists in the form of several biological races. Varieties showing resistance to one race are not necessarily resistant to other races. It is, therefore, necessary to breed for resistance to all known races of the rust.

The third major development has been in relation to spring wheat varieties. The last twenty-five years have seen a spectacular improvement in yielding ability and straw-strength, although in neither attribute are they yet the equal of the better winter wheat varieties. Varieties like Atle, Atson, Svenno and, to a less extent, Koga II, in addition show high milling and baking quality.

Along with the developments mentioned attention has been given to resistance to other diseases, such as Loose Smut (*Ustilago tritici*) and Mildew (*Erysiphe graminis*), to resistance to shattering of the ear at harvest, to resistance to sprouting in the ear, and to date of maturity.

Position in Rotation. Wheat is frequently grown after a one-year seeds or longer ley on medium to heavy loam soil ; on the really heavy clay land, it may be taken after a fallow, bastard fallow or after peas or beans. Because the straw is relatively strong and resistant to lodging, wheat on many farms is taken after potatoes or after roots when the level of fertility is often too high for the other cereals. Moreover, under rich conditions the quality of the grain does not suffer as in the case of barley, nor does the yield suffer at the expense of straw production as often happens in the case of oats. It is not customary to take winter wheat as a second straw crop, although in recent years two, or even three, winter wheats have been taken after ploughed-out grass and leys. Spring wheat quite frequently is taken as a second straw crop. There is, of course, the example of continuous cropping with winter wheat over the last 114 years on the famous Broadbalk field at Rothamsted. A succession of wheat crops, or indeed too many wheat and barley crops, in a rotation can give rise to disease troubles. The chief of these are Eyespot and Take-all (see pp. 389 and 372).

Where such trouble has been encountered a two- or three-year rest from wheat and barley is necessary in the case of Eyespot, but a one-year gap is all that is needed in the case of Take-all, provided the land is free from Couch grass and Yorkshire Fog, which can also carry the disease. Three-year breaks in the rotation may be made either by introducing medium-duration leys or by re-arranging cash crop sequences to give, for example, oats—seeds—potatoes, or other three-year non-wheat-non-barley sequences (see p. 204).

Manuring. As with other crops, the yield of wheat depends to a very large extent upon the availability of adequate quantities of the three main plant nutrients, nitrogen, phosphate and potash. In former times these were applied mainly in the form of farmyard manure. In rotations where wheat followed seeds the F.Y.M. was usually applied at rates from 6 to 10 tons per acre on the seeds before ploughing. This practice is still followed at the present time in some areas. In others, the F.Y.M. available tends to be reserved for crops such as potatoes. After heavily manured and fertilised crops, residues are available for the wheat crop, and this reduces the quantity of other fertiliser required.

According to the Crowther and Yates system of calculation of average optimal fertiliser rates, those for the wheat crop, under the price structure of the last few years, and taking account of subsidies, have been as follows :

Nitrogen.	Phosphoric acid (P_2O_5).		Potash (K_2O).
70 units/acre *	S.E. England	14 units/acre	17·25 units/acre
	N + W ,,	24 ,, ,,	
	Wales and Scotland	34 ,, ,,	

* The unit referred to here, and elsewhere in this and subsequent chapters, is 1/100 cwt., or 1·12 lb. (see p. 186).

The average optimal for phosphoric acid, unlike that for nitrogen and potash, varies according to climate regions and is greater in the wetter and lower in the drier areas. These figures represent a basis from which reasonable fertiliser dressings for the crop can be worked out.

The 70 units of nitrogen represent the average optimal rate, provided the crop will stand such a dressing without lodging. Crowther and Yates originally suggested that an arbitrary upper limit of 40 units per acre only should be used because the varieties in use 20 years ago were insufficiently strong in the straw to stand up to the full dressing. The position has changed with the availability of stronger strawed varieties. Extensive experimental work in recent years has shown that for varieties like Cappelle Desprez and Hybrid 46, 70 units per acre is optimal, but for other varieties 50 to 60 units per acre are more appropriate for average conditions. Three factors other than varietal strength of straw affect the standing ability of a crop and therefore its ability to make use of high levels of nitrogenous fertilisers. One is seed rate, a low seed rate giving greater straw strength ; a second is an infection with the fungus causing Eyespot which reduces straw strength ; a third is the moisture factor as influenced by climate and soil, the moister conditions giving rise to a relatively longer straw.

Residues of plant nutrients applied to previous crops, and still available to the wheat crop, influence the actual rates of fertiliser required. Where wheat is taken after a well-manured potato crop even Cappelle Desprez only requires 40 units of nitrogen and certainly no phosphate or potash. Farmyard manure applied when ploughing out one-year clover seeds or a sequence in which the crop follows a good ley, also reduces the fertiliser requirement for wheat. The type of soil modifies the fertiliser requirements. For instance, wheat grown on true fen peat soil will require less nitrogen than the average optimal owing to the nitrogen content of these peats. On soils deficient in phosphate or potash supplementary dressings of the appropriate fertiliser are required over and above the average optimal.

Methods of application of the fertiliser to the crop require special mention. In most cases little or no nitrogenous fertiliser is required in the autumn with winter wheat. The optimal rates refer to that applied as a top dressing in the spring in the form of sulphate of ammonia or other ' straight ' nitrogen fertiliser. As a general rule these top dressings should be given as late as reasonably possible, often about the beginning of May. In the dry eastern counties there is evidence that a split dressing, half early and half late, can be an advantage. If all the top dressing is given in early spring excessive growth of straw is liable to occur. In the case of the spring crop the nitrogenous fertiliser may be incorporated in the seed-bed or part placed in the seed-bed and the rest given as a top dressing.

Phosphatic and potassic fertilisers, usually in the form of compounds, are applied to the seed-bed prior to sowing, both in the case of the autumn- and spring-sown crop. With the phosphate, and to a less extent the potash, component of the fertiliser, the practice of combine drilling has been shown to give considerable advantages over broadcast applications. A large series of experiments carried out in many English counties, showed that 27 units of phosphoric acid placed in contact with the seed gave equal crop responses to 54 units per acre broadcast. With wheat, as with other cereals, the type of combine drill where seed and fertiliser go down the same spout is satisfactory provided ordinary rates of fertiliser are used.

The yield of grain in wheat depends to a great extent on the number of tillers which produce ears at harvest. Blind tillers, i.e. those which fail to produce ears, are useless, and those which develop late in the season usually yield badly or not at all. Production of the maximum number of ear-bearing tillers is not only dependent upon early sowing but also upon the supply of plant food : for this reason ammonium phosphate or a mixture of sulphate of ammonia and superphosphate applied at seeding time is sound practice. A further application of a nitrogenous fertiliser, say 3 cwt. per acre sulphate of ammonia or 4 cwt. ' Nitro-Chalk,' applied in late spring (i.e. the end of April or the beginning of May) will help to increase the size of the ear, and hence the yield of grain, without increasing the risk of lodging. Phosphates, in contrast to nitrogen, help to encourage root development.

Cultivations. The type of seed-bed considered desirable for cereals differs considerably depending upon whether the cereals are spring or autumn sown. With a spring-sown cereal the standard aimed at is one where the soil is reduced to a fine crumby tilth, free from clods and firm enough to prevent the heels of one's boots sinking in when walking over it. For the sake of economy and also to minimise the loss of moisture from the surface layers, the specified seed-bed should be achieved with the minimum cultivations possible. To do this it is necessary on all but very sandy soils to plough the land sufficiently early to obtain the mellowing effects of alternate freezing and thawing and alternate wetting and drying. " Forcing " a tilth refers to the excessive cultivations required to produce a fine tilth on the heavier soils ploughed too late to receive the benefit of weathering. Where the necessary standard of fineness and firmness is achieved with minimum loss of moisture, the resulting germination of the seed and early growth of the crop are uniform and as rapid as the prevailing temperature permits. Where the tilth is coarse, where it lacks firmness or where there is undue loss of moisture due to forcing a tilth, uneven germination results and there is usually a reduced plant population established from the seed sown.

In the seed-bed for an autumn-sown cereal firmness is also a desirable characteristic. This kind of seed-bed requires a certain amount of fine crumby material in it, but in addition it is considered that an appreciable quantity of fist-sized clods are required. The latter have the effect of preventing the " panning " or " capping " which occurs when a uniformly fine seed-bed is exposed to the winter rains. Where capping occurs, free gaseous interchange between the soil air and atmosphere is checked, often to the detriment of plant growth. In addition it is often considered that the clods give a measure of protection to the young plants from cold dry frosty winds of the winter.

The spring cereal type of seed-bed can usually be prepared easily enough by harrowing, or a combination of rolling and harrowing, provided the plough furrow has been sufficiently mellowed. In the special circumstances where a spring sown crop follows ploughed-out grass or ley, it is advisable to use disc harrows for the first cultivations following ploughing.

For autumn seed-bed preparation fewer cultivation operations are required. After ploughing, drag harrows only are used in most cases, but discing is also common. Rolling is not necessary and in fact is likely to crush too many of the clods. On soils liable to " puff out " over the winter, as for instance the chalk soils, it was formerly customary to use a press drill or a furrow press. These are still used in some districts. Disc harrows are used when taking wheat after ploughed-out grass or ley. Where the crop follows clover seeds, an aftermath growth is often ploughed in and this needs to be done with care so that the green material is completely buried. Skim coulters and drag chains may help to bring this about. After peas, beans or another cereal crop, stubble cleaning may be necessary prior to ploughing. After peas, clover seeds, or a cereal-legume silage mixture, a bastard fallow may be possible. After potatoes the land is usually clean and the soil fine and loose in texture. In many cases no further preparation is required beyond a turn of the cultivator before drilling. Frequently this results in a seed-bed which is too fine. For this reason the land is often ploughed and re-worked down ; an old practice was to broadcast the seed on the surface and plough it in with a very shallow furrow—a practice known as " shelling in ".

Sowing. The sowing is usually carried out with a drill having coulters spaced 6–8 in. apart : the seed is buried to a depth of about 1½ in. Sowing too deep leads to delayed emergence and, sometimes, to unsatisfactory establishment. Seeds placed at considerable depths (say 4–5 in.) may completely fail to emerge. Seeds sown too shallow may remain in a relatively dry layer of soil and show irregular germination. Sowing by broadcasting on an incompletely prepared seed-bed, such as may be necessary under adverse circumstances in the autumn, leads to some seeds being too deep and some too shallow. As a precautionary measure against seed-borne diseases the seed should be dressed with one of the many organo-mercurial seed powders (see p. 382). Where there is reason to suspect a high wireworm population, such as when wheat is taken after ploughed-out grassland, it is advisable to use one of the combined insecticidal-fungicidal seed dressings. The latter form of seed dressing can also give a measure of control against wheat bulb fly (see p. 431).

In practice the quantity of seed sown depends upon a number of factors such as time of the year, the quality of the tilth, the district and the germination percentage of the seed. There is, however, a definite relation between seeding rate and yield. Up to a point, increases in seed rate increases the grain yield ; beyond this point further increases in the seed rate lead to decreases in grain yield, although straw yields may continue to increase. This point where the change in response takes place is called the physical optimum seed rate. Experimental work in recent years has shown that the average physical optimum seed rate for grain yield of winter wheat is 1½ cwt. per acre and 2 cwt. per acre for spring wheat. The economic optimum seed rate is less than the physical optimum and will vary according to the relative value of seed and crop, weight for weight. Where the farmer uses his own seed and therefore the seed and the crop are both of the same value, the economic optimum seed rate is 1¼ and 1½ cwt. per acre for winter and spring wheat respectively ; where the seed value is twice that of the crop the optimum will be 1·12 and 1·1 cwt. per acre, and where the seed value is three times the crop value the optimum will be decreased to 1 cwt. per acre for both wheats. These average optima can be taken as working guides. With abnormally late planting, with seed-beds of unsatisfactory standards, where the germination percentage is low or where broadcasting is used in place of drilling, the actual seed rate needs to be greater than the average optima.

Date of sowing is an important matter with the wheat crop. It is not advisable to sow autumn wheat too early. The middle of October is the time to commence sowing in many areas, and it may be continued up to mid-November. Sowing earlier than mid-October may, where followed by a mild winter, lead to excessive vegetative growth or " winter proudness ". Such excessive growth is liable to cause subsequent lodging of the crop, either directly or indirectly, by facilitating the spread of Eyespot disease (see p. 389). A true winter variety should not be sown in the spring although the earlier maturing types may be sown up to mid-February. Sowing later than mid-February may mean a complete failure of the crop to produce ears.

With spring wheat, drilling as early as possible is the rule. This usually means as soon as the land is dry enough to work down to a tilth during the period January to March. If weather delays sowing the crop until April, one of the early ripening varieties, such as Svenno, should be used.

Post Drilling Cultivations. When wheat is examined in the early spring, it may be discovered that frost has lifted the surface soil on some fields and that the plant is loose at the root. On other fields the soil may be panned down and set into a hard, compact crust. Frequently seedlings of annual weeds will be growing. To rectify these conditions either rolling or harrowing or both will be necessary : but these operations must not be carried out until the soil is dry enough to carry the implements. If the weed infestation is likely to affect the corn crop a suitable weed killer should be used. The choice of weed killer should be determined according to the dominant weed species to be controlled. Information on this matter is given in Appendix VI.

If " winter proud " growth has occurred the excessive leafage may be grazed with sheep or cattle. If stock are not available, spraying with sulphuric acid, or mowing, has a similar effect. Treatment of excessive growth should not be done later than the end of March or severe yield depressions are likely to occur. The feeding value of the leafage is by analysis similar to that of young grass, but deteriorates both in feeding value and palatability during April. Winter proudness is best regarded as a condition to avoid by attention to sowing date, and spring grazing should only be considered as a means of alleviating the worst effects of an undesirable condition.

Harvesting. Two methods of harvesting the wheat crop are used in current practice ; one is the older binder-harvesting technique and the other the more highly mechanised technique based upon the combine harvester.

The Binder. With the binder the crop is cut before it reaches the dead ripe stage whilst the grain is still in the " cheesey " condition. Immediately after cutting, wheat should be stooked 8–12 sheaves to a stook. The sheaves should be set with the butt ends firmly on the ground, the ears forming an acute angle so that the rain is quickly shed. It is customary to run the stooks North–South for the sake of even drying. The stooks need to remain in the field from 7 to 14 days, during which time grain maturation is completed. The time in stook depends upon the condition of the crop when cut, whether there is much green stuff in the sheaves and also upon prevailing weather conditions. Ideally it is carted when perfectly dry, although once it is properly mature, carting may proceed even if some surface damp from dew is present. The stacks should be constructed on a dry base and preferably one which allows air to circulate freely below the rick. In building the stack it is important to keep the centre higher than the walls, with all the sheaves sloping downwards and outwards ; in this condition the rain, if it beats against the side of the stack, does not run in and cause damage. The roof should be particularly well built, keeping the centre well hearted and placing the outside sheaves so that the butts overlap like slates on a roof. If the stacks are made in the open they should be thatched soon after completion.

In favourable seasons, more especially in the South of England, threshing may be done directly from the field with a considerable saving in man-hours on the harvesting operations. In the stack the grain may sweat slightly and, should it have been carted in bad order, it may be necessary to leave it to dry out in the stack until the spring before threshing. The threshing machines used in this country are usually of the beater-bar type which gives an efficient separation of grain from straw, chaff and weed seeds (see page 152). The straw is not damaged appreciably and can be used for thatching. The peg-drum American and Canadian types of machines also give an efficient separation of grain, and there is, in addition, a higher output with less labour than from the English machines. The straw, however, is badly shattered and useless for thatching.

The Combine. An increasing acreage of wheat is now being cut and threshed by combine harvesters. At the present time approximately three-quarters of the crop is harvested in this way. The main advantage of the system is that the whole of the harvest operations are completed quickly with a considerable saving in terms of man-hours compared with the binder-harvest system. As the crop must be dead ripe before combining it is essential to use a variety which is not prone to shattering. Although the crop has to stand uncut for a longer period than when the binder is used, it is not on that account any more vulnerable to bad harvest weather. Field experience, in fact, has shown quite the opposite. In a wet harvest a standing crop will dry out rapidly in the short drying spells whilst a stooked crop will remain wet and unfit for carting. Lodged crops, although always a nuisance, can be harvested more efficiently with the combine, particularly the self-propelled type, than by the binder. As the speed of the combine is determined to a large extent by the volume of straw passing through it, it is usual to leave longer stubbles than with the binder. This factor also re-emphasises the necessity for cereal varieties with a high ratio of grain to straw to obtain the best field efficiency.

The facilities available for handling and drying, or for direct sale of the wet corn from the farm, dictate the moisture content at which the crop is combined in the field. Data for safe moisture contents for storage as well as other field aspects of the technique of using combine-harvesters are given on page 91. The combine harvester, together with the grain drying and storage equipment, does of course involve considerably greater capital cost than binder equipment. On the other hand the saving in man-hours is approximately 50 per cent.

Figures quoted from economic surveys in the Ministry of Agriculture publication entitled "The Farm as a Business" are as follows :

MAN HOURS PER ACRE FOR HARVESTING WHEAT

Combine Harvesting (includes handling of straw).		Binder Harvesting (includes Threshing).	
Self-propelled. 12 ft. cut.	Towed. 5 ft. and 6 ft. cut.	Stacked and Threshed.	Threshed in Field.
9·3	11·7	23·6	14·4

Straw collection after the combine harvester is usually done from the windrow by pick-up balers. Any green material in the windrow should be allowed to dry before the pick-up baling is done. Some combine harvesters are fitted with straw trusses which eliminates the need for a separate pick-up baler. Trusses of this type are not so suitable in a crop which contains green material in the straw. It is convenient to tow a bale sledge behind the pick-up baler so that the bales can be collected into 6- or 8-bale stacks. These small stacks render the bales less vulnerable to wet weather, they allow wet bales to dry out, and they facilitate carting.

The combine harvester system has introduced rather a different attitude to straw in the economy of the farm. Under the binder systems, except where threshing was done in the field, the straw was transported to the buildings along with the grain. The straw so collected had to be disposed of in some way, either to stock or for sale from the farm. With the combine harvester technique the straw need only be collected if it is required either for stock or for sale. If it is not required it may either be burnt *in situ* or ploughed in according to the beliefs held as to its value for soil fertility. If it is to be ploughed in, a spreader fitted to the combine harvester and "wavy" disc coulters fitted to the plough facilitate the operation.

Yield. The average yield of wheat in this country has been steadily increasing due to the introduction of stronger strawed varieties with a higher yield potential, and to higher rates of nitrogenous fertilisers applied to the crop. The average yield in the 1930–40 period was 17·9 cwt. per acre : the five-year averages since that time are as follows : 1940–44, 19·1 cwt. per acre ; 1945–49, 19·3 cwt. per acre ; 1950–54, 22·9 cwt. per acre ; 1955–59, 26·1 cwt. per acre. It is by no means exceptional to have grain yields of two tons per acre and more. Wheat growers in the good cereal growing soils in the east of the country expect to have yield averages between 1½ and 2 tons per acre according to season. In field practice and in some experiments, yields of over 3 tons per acre have been recorded.

The straw yields accompanying these grain yields will vary between 25 and 30 cwt. per acre.

BARLEY

In barley the glumes are relatively small and insignificant and the spikelet contains one floret only: the paleæ, which form the "skin" of the grain, are fused with the caryopsis, or true kernel in most of the varieties grown in this country. There are, however, species of barley with naked grains. As with the other cereals there is a large number of species and varieties but, from the British farmer's standpoint, two main species only are of importance, Six-rowed barley (*Hordeum polystichum*) and Two-rowed barley (*Hordeum distichum*). The area devoted to the six-rowed barleys, however, is very small compared with that sown with the spring varieties of two-rowed barley.

In the six-rowed barleys three fully fertile spikelets arise from each node of the rachis; the same arrangement is found in the two-rowed barleys, but here only the middle or median row of the three spikelets is fertile and forms a grain. The median rows of spikelets in both species have their ventral surfaces, i.e. the surface with the furrow, opposed to the broad side of the rachis. The other spikelets are attached to the node nearer the edge of the rachis, and in six-rowed forms the grains are consequently not absolutely symmetrical in longitudinal section, but slightly twisted (Fig. 32). Since to each set of three spikelets there is only one median grain, six-rowed varieties have one row of median and two rows of lateral spikelets on each side of the rachis, the complete ear having two rows of median and four rows of lateral spikelets. In two-rowed varieties there is one row of fertile and two rows of infertile spikelets on each side of the ear, the complete ear having two rows of fertile and four rows of infertile spikelets.

Varieties. Six-rowed barleys are not much grown in these islands, although in Scotland both winter-sown and spring-sown types are cultivated under the names of "Bere" or "Big". Most of the plant breeding work has therefore been concentrated upon the two-rowed barleys, although the Cambridge Plant Breeding Institute did produce a winter-hardy six-rowed barley known as Prefect which is now obsolete.

Malting quality and general agronomic characteristics have both had their influence upon the barley breeding programmes. As in the case of wheat, the first success of the plant breeder was in pure line selections from the old land race varieties. In this way the varieties Archer, Chevallier, Plumage and Spratt arose and dominated the scene for many years. The next phase of development was hybridisation between these types in order to combine desirable characteristics. This led to the two famous varieties—Spratt-Archer, produced by Dr. Hunter in Ireland, and Plumage-Archer, produced by Dr. Bevin at Warminster. These varieties were both brought out in the early 1920's, they both had good malting qualities and, by the former standards, were high yielders. These two varieties dominated the acreage grown through the late 1920's and the whole of the 1930's. They remained upon the recommended list of the N.I.A.B. until 1960. Few varieties of any cereal have enjoyed such a long period of success as these (see also Chapter XV).

Early in the 1930's the Danish variety, Kenia, was introduced and this was followed by Maja, Freya, Herta, Rika and Carlsberg. All

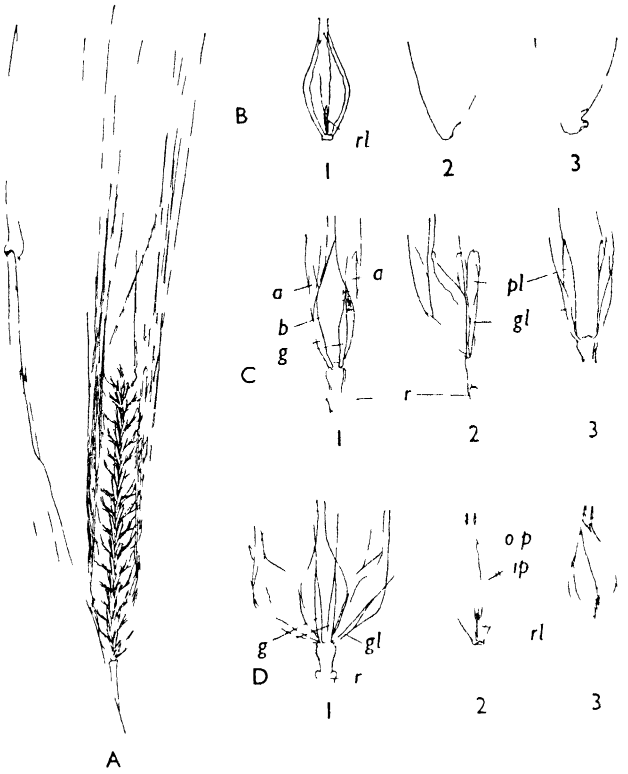


FIG 32—EAR OF BARLEY

A Typical ear of two-rowed barley

B Grains of two rowed barley ventral and side views

B1 ventral view of grain B2 chisel edge base to grain of drooping eared type B3 "lumpy" base of erect eared type

C Structures at rachis notch of two rowed barley

C1, C2, central (fertile) and lateral (sterile) spikelets. C3, glumes and pales of lateral spikelets (central spikelet removed).

D. Structures at rachis notch of six-rowed barley.

D1, triplet of fertile spikelets. D2, symmetrical grain of central spikelet. D3, twisted grain of lateral spikelet. *r*, rachis. *rl.*, rachilla. *a*, sterile lateral spikelet. *b*, grain of fertile spikelet, *g*, glumes of central spikelet. *gl.*, glumes. *pl.*, pales of lateral spikelet. *o.p.*, outer pale, *i.p.*, inner pale.

these varieties had shorter and stiffer straw than Plumage-Archer and Spratt-Archer. Their yield at low levels of fertiliser use was not much superior to the English varieties, but by virtue of their stiffer straw more fertiliser could be used and, as a result, their yield potential was much greater. Their malting quality, however, was considered to be inferior to the English types. Because of the superior agronomic merits of these Scandinavian varieties, crosses were made between them and the English varieties in an attempt to combine the virtues of each into new varieties. This programme led to the production of Maythorpe, Proctor and Provost, all products of the Cambridge Plant Breeding Institute. Of the three, Proctor has been the most successful and now dominates the market. Another feature of the Scandinavian varieties was their earliness of ripening compared with

Plumage and Spratt-Archer. A further development due to hybridisation has been the combination of high malting quality with winter hardiness in Pioneer.

A present trend in barley breeding is directed to producing a malting variety with the agronomic characteristics of Proctor but with earlier ripening. A further trend is to produce varieties resistant to cereal mildew (*Erysiphe graminis*). It has been shown that this disease can give greater yield depressions than was formerly supposed, and thus breeding for resistance assumes greater importance. In the future, no doubt, work will be directed to breeding for the physiological components of yield.

For the description of the recommended varieties the leaflets produced by the National Institute of Agricultural Botany at Cambridge should be consulted. The recommended varieties change from time to time as new varieties are produced. The present recommended varieties are listed in Appendix V.

Malting Quality. Approximately one-quarter of the barley crop produced in this country is used for malting and the remainder goes for stock feeding. Since there is usually an appreciable price differential for malting barley the characteristics of a good malting sample need to be outlined. Unlike wheat, quality in barley is to some extent incompatible with high yield. The new Cambridge hybrids have reduced this incompatibility to some extent but have not eliminated it, as less fertiliser nitrogen must be used to obtain the highest malting quality. Malting barley must contain a high proportion of starch and a small proportion of protein because it is from the starch that the brewer ultimately obtains maltose, and it is this material that later, when in solution and acted on by yeast, produces a fermented liquor. A cross-section of a good malting sample shows a white " mealy " interior, whereas one with a high nitrogen content will have a translucent or " steely " interior.

The physical features of the grain are usually the guide as to whether a sample of barley is fit for malting or not. In the first place the grain must have been well harvested, be free from excessive moisture and have a sweet smell with no hint of mustiness. Great care is also necessary in threshing, for any skinning or fracture of the grain will ruin its germinating capacity and hence its value for the maltster. It should be even in size, with an evenly coloured and finely wrinkled skin indicating good harvest weather and the right stage of maturity. The sample should also be clean and free from weed seeds or any trace of fungus disease.

To attain this degree of perfection necessitates a good climate, avoiding such extremes as very dry, sunny weather, and wet, sunless weather. Excessive drought after flowering leads to premature death of the plant and small, shrunken and often steely grains, resulting from incomplete translocation of the starch from the straw. Cool wet conditions delay the grain maturation process and lead to discoloration of its surface. Before the grain is fit for malting it must undergo a complete drying-out process (i.e. down to about 14 per cent moisture), otherwise it is likely to exhibit dormancy and give delayed germination on the malting floor.

Soil, too, is a factor of great importance in obtaining malting quality and here, irrespective of rainfall, it is found that heavy soils do not yield the best malting samples. The ideal is a fairly rich medium loam in a district of moderate rainfall. Very light soils produce excellent barleys when the precipitation is adequate, but usually fail in dry years. Soils of reasonable depth derived from chalk, or other calcareous rocks, have the highest reputation as good malting barley soils.

Position in Rotation. Barley is normally taken at two points in the traditional rotations : as the spring cereal crop following a folded root crop ; and as a second straw crop, usually after wheat. In many parts of the country barley is now taken after a sugar beet crop. It was formerly inadvisable to take barley after potatoes, but with the stronger strawed varieties this is now a much safer procedure though it is a sequence only suitable for feeding-quality barleys. Barley is a crop not able to stand up well to weed competition and this was one of the reasons for taking it after turnips or swedes. With the modern range of chemical weed killers there is now less need for this sequence, and the practice of taking barley as a second, or even third, straw crop has increased considerably. There are examples of successful continuous cropping with barley to be seen on Hoos field at Rothamsted, and formerly on the chalk land farms belonging to the late Mr. Chamberlain of Oxfordshire. Barley is probably the safest of the cereals to be cropped at a high frequency in a rotation because of its relative freedom from serious rotation diseases. Eyespot, although able to attack the crop, rarely becomes a serious trouble except with winter barley. Barley is also susceptible to Take-all, but a one-year rest from wheat or barley is sufficient to control the disease provided there is no Couch grass, Yorkshire Fog or volunteer wheat or barley plants. In recent years cereal root eelworm has attacked barley, and this pest must be regarded as a potential threat to intensive barley cropping.

Seed-bed Preparation. The seed-beds prepared for the autumn sowing of barley are similar to those for wheat, but for spring sowings much greater care is necessary in their preparation—partly because dry weather conditions may follow the sowing, during which a badly prepared seed-bed is liable to dry out in parts and give rise to an irregular plant. A further factor necessitating additional care in cultivation is the shorter interval of time between sowing and harvesting, which means that everything possible conducive to even germination and rapid development must be done. In the case of autumn sown crops, time and weather help to ameliorate irregularities in the germination of the seed, but in the case of spring-sown crops this latitude is not possible. In the latter case the typical spring cereal type of seed-bed is required with its fineness and firmness achieved with minimum loss of moisture. For this purpose the initial ploughing does not need to be very deep but, on soils other than the lightest, it requires to be done early enough to obtain the mellowing effect of alternate freezing and thawing. Subsequent working down with harrows, or harrows plus Cambridge roller, will then achieve a seed-bed of the desired standard with the minimum of operations.

Great care is necessary when preparing the seed-bed after late folded roots, for at this time of the year dry weather is likely to prevail and there is a danger of the seed-bed drying out completely during its preparation. Time does not permit of two ploughings, whilst one deep ploughing would turn the damaged surface soil down to the subsoil in an unweathered condition. In the circumstances the normal procedure is to plough shallow, and roll and harrow each day's ploughing immediately afterwards so that the furrows are left covered with a little fine soil which prevents them drying out before ploughing is completed. Alternatively, disc harrows may be used on the trampled surface before ploughing in an attempt to ameliorate the poached surface. This operation should be carried out when the soil begins to dry. Then the land is ploughed to a shallow depth so that the friable surface soil falls upon the subsoil as the furrow is turned. The area ploughed each day must be rolled and harrowed whilst still retaining sufficient moisture for the soil to be crumbly. Final touches to the seed-bed can be given with disc harrows and roller, when the result should be a uniform tilth to the full working depth.

When barley is taken as a second, or third, straw crop every opportunity should be taken to destroy perennial weeds by stubble cleaning operations. This may be achieved by broadshare cultivation or shallow ploughing. If done immediately after harvest, in many years a kill of the weed rhizomes may be obtained by desiccation. In a very foul stubble these operations may be followed by the use of the drag and chain harrows to pull the rhizomes to the surface and collect them for burning—in fact the traditional set of " wicking " operations. Where soil conditions are suitable many farmers prefer the technique of deep ploughing as a control of perennial weeds, and in some circumstances rotovating has been found to be a useful stubble cultivation technique. If the problem is an annual weed instead of perennial infestation, the stubble cultivations should be aimed at producing a seed-bed to encourage the buried weed seeds to germinate. These are subsequently killed as seedlings by ploughing. This is a very necessary practice in the case of annual weeds which cannot be controlled by selective weed killers, and it is one of the few techniques that can be used in the case of wild oats.

Manuring. Barley is the most sensitive of the cereal crops to soil acidity. Failure is likely to occur at pH 5·3, and reduced yields and lowered quality may be expected at acidities below pH 6. Thus any suspicion of soil acidity should be rectified by liming before a crop of barley is sown. It is advisable to do this well before the crop is drilled so that the lime may be given sufficient time to act. Undoubtedly the best procedure is to apply the lime to the preceding crop ; failing this, every attempt should be made to apply in the autumn before the barley is sown.

The review of experimental data made by the late Dr. Crowther and Dr. Yates suggested that the theoretical average optimal fertiliser requirements (see p. 222) for the crop was similar to that obtained for the wheat crop, namely 70 units of nitrogen ; 14, 24 or 34 units per acre according to district of phosphoric acid ; and 17 to 25 units per acre of K_2O. There are, however, two features of importance in which barley differs from the wheat crop. One is that the resistance to lodging due to high levels of fertiliser nitrogen is less in the strongest strawed barleys than in the equivalent wheat varieties. There are circumstances where the full theoretical optimal of 70 units per acre of nitrogen may cause lodging, even when lower rates of seeding than the normal are used. The second is that high soil nitrogen has a retarding influence upon grain maturation and hence upon malting quality. The customary dressings tend to be 40 to 60 units of nitrogen per acre for strong strawed varieties where feeding samples only are required, and 20 to 40 units per acre where malting samples are aimed at. The new hybrid barleys, as well as the Scandinavian varieties, not only have a higher average yield, but also have an intrinsic ability to respond to a greater degree to nitrogenous fertilisers than the older varieties, Plumage-Archer and Spratt-Archer. To achieve good malting samples from them, however, the grower must be just as cautious with levels of nitrogenous fertilisers as with the latter varieties. Where barley is taken after a crop of roots folded off, the level of nitrogen applied should be reduced by about 30 units, and the P_2O_5 and K_2O by 20 and 25 units respectively. In many cases this means no P_2O_5 or K_2O need be applied after a folded crop.

Time of application of the nitrogen is also of importance. With spring barley intended for malting all the nitrogenous fertiliser should be applied before sowing and worked into the seed-bed. With a feeding barley some farmers put half in the seed-bed and half as a top dressing later in Spring. Recent experimental work, however, has shown that the best responses are obtained when all the nitrogen is placed in the seed-bed ; it has also shown that it is safe to combine-drill this relatively high rate of nitrogen. With winter barley intended for malting, the nitrogen, usually not more than 1 to 1½ cwt. of sulphate of ammonia, should be applied as a top dressing early in April.

Where the soil is known to be deficient in phosphate or potash it is necessary to increase the quantities given over and above those specified as the average optimal dressing. It is usual to give the barley crop greater rates of phosphoric acid than the theoretical optimal unless it follows a folded root crop or sugar beet crop. This is probably sound practice in the case of malting barley on soils other than the lightest in the low rainfall areas. It has been shown that phosphate has a very beneficial effect upon grain maturity and hence upon malting quality.

Barley is the most resistant of the cereals to a low potash status of the soil. Yet in general practice it is the cereal which receives the greatest amount of potash fertiliser. One reason for this apparent anomaly is that it is the cereal most commonly grown on the chalk and limestone soils, many of which have abnormally low potash status. Care is needed with potash levels for the malting crop ; excessive quantities have an effect upon grain maturation, and hence malting quality, similar to excessive amounts of nitrogenous fertiliser. Combine drilling of phosphate and potash leads to similar increases of efficiency of the plant nutrients as in the wheat crop (see p. 223).

Organic manures are not normally applied directly to the barley crop. In many rotations the crop receives the benefits of organic residues from folded root crops and from folded or ploughed-in sugar beet tops.

Sowing. Seed barley should consist of a plump, even grained sample of good germination, and it should be free from impurity. It should be dressed with an organo-mercurial powder as a precautionary measure against Leaf Stripe and Covered Smut diseases (see p. 384). If there is a high wireworm population in the soil a combined organo-mercurial-insecticidal seed dressing should be used.

Drilling should be to a depth of 1–1½ in. below the surface, on a firm bottom : it is normally carried out with drills having 7 in. coulter spacings.

Winter varieties, such as Pioneer, should be drilled in late September or early October ; that is earlier than the winter wheat crop. Spring varieties may be drilled from January to April according to the state of the ground. The crop is often drilled in February in the drier south-eastern counties, but in the north it is rarely possible before March. Drilling as early as is consistent with attainment of suitable seed-bed conditions is the rule. Both yield and malting quality benefit from early sowing. In sheltered areas near the sea, spring varieties are sometimes sown as early as December : there is some risk attached to this practice as these spring varieties are not truly frost resistant.

The usual rate of seeding is 1½ cwt. per acre but, as with wheat, recent trends have been to reduce seed rates. As with wheat, barley shows a point of physical optimum seed rate ; seed rates above and below this optimum give reduced yields. Recent summaries of experimental work have shown that the average physical optimum seed rate occurs at 1¼ cwt. per acre. Where the farmer is using his own seed 1¼ cwt. of seed is also the economic optimum ; where the cost of the seed is twice the price received for the crop, weight for weight, the economic optimum is 1 cwt. per acre. Again, these figures should be taken as general guides only. They need to be increased where drilling is late or where the seed-bed is below standard. With malting barley it is probably inadvisable to decrease the seed rate below 1¼ cwt. per acre. With feeding barleys the lower seed rates quoted have the advantage of making the crop less liable to lodge with high rates of fertiliser nitrogen.

After drilling, the crop is harrowed in and, on the lighter soils, is usually rolled. If a weed infestation problem arises the crop may be sprayed with one of the selective herbicides (see p. 212 and Appendix VI).

Harvesting and Threshing. The application of full mechanised harvesting has been particularly successful with barley and approximately three-quarters of the crop is dealt with in this way. Using the binder technique approximately 27 man hours are required to produce and harvest the crop ; with combine harvesting the figure is reduced to approximately 15 man hours per acre. There is still a certain amount of prejudice amongst maltsters and seedsmen against samples of barley harvested by combine harvesters, but this is gradually decreasing.

When combine harvesting, both feeding and malting barley must be left until dead ripe before cutting commences. Where malting barley is harvested by the binder it similarly must be dead ripe before cutting. There is, however, greater latitude concerning the date to cut when a feeding barley is harvested by binder. Barley varieties are not so liable to shed grains by shattering when dead ripe as are wheat varieties. On the other hand severe winds may shear off whole ears at this stage causing severe loss of crop. This is more likely to occur in those varieties having a long " neck "—that is to say, a long length of straw protruding above the uppermost leaf sheath. Crops which, after the dead ripe stage, develop a form of false lodging characterised by a sharp bending over of the straw half-way between ground and ear, are less vulnerable to such damage. Great care is required in the storing and drying of the grain of malting barley after combine harvesting. Further reference should be made to page 91 for details. Many maltsters prefer to buy malting barley direct from the combine and do their own drying and storage.

When harvested by binder the crop is stooked in the field and subsequently stacked. Where a crop of malting barley is cut when dead ripe there is no need for a period of maturation in the stook. The crop can therefore be carted and stacked as soon as dry enough.

In the threshing of the barley crop intended for malting great care is needed in the setting of the threshing machine or combine harvester for the reasons already discussed in detail on page 231. A little of the " beard " left on the grain is not a drawback and is regarded as an indication of careful threshing.

Yield. The extended use of the stronger strawed varieties, together with the high rates of fertiliser their use permits, has resulted in a gradual increase of the average yields of barley in recent years. The mean yield between 1930 and 1940 was 16·0 cwt. per acre ; the following are the five-year means since 1940 : 1940–44, 17·3 cwt., 1945–49, 18·4 cwt. ; 1950–54, 20·6 cwt. ; 1955–59, 24·1 cwt. per acre. On good soils and in good seasons yields from 30–40 cwt. per acre are common and yields considerably in excess of 2 tons per acre have been recorded.

The yield of straw in the barley crop is usually about equal to that of the grain with the older varieties, but it is less with the newer varieties.

OATS

The inflorescence of oats differs markedly from those of wheat, barley and rye, in that the divisions of the rachis are measured in inches instead of fractions of an inch and the spikelets are not borne directly on the rachis but either on branches of varying length arising directly from the nodes of the rachis, or on secondary branches arising from the primary branches. This type of ear is called a spreading panicle (Fig. 33). The manner in which the spikelets are joined to the pedicels, or small branches, is important, and is one of the features used to distinguish different species. Thus, in some species there is a distinct cavity at the base of the grain, the edges of which

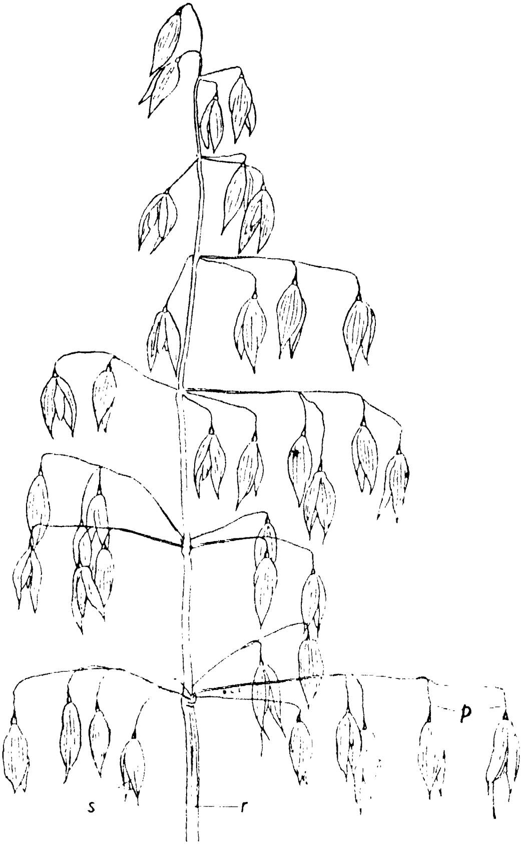


FIG. 33.—SPREADING PANICLE OF OAT.
r, rachis. *p*, pedicel. *s*, spikelet.

are well defined, and frequently bear a ring of strongly grown hairs. The extremity of the pedicel is expanded into a knot which fits into this basal cavity, the two thus simulating a ball-and-socket joint. Such an arrangement is found in *Avena fatua*, the wild oat of cultivated land, and in *Avena sterilis*, another wild form, indigenous to the countries bordering the Mediterranean. On ripening, the tissue connecting the pedicel and grain separates naturally, and the grain thus detached from its pedicel is shed on to the soil, thereby assuring continued propagation.

Most of the cultivated varieties found in the British Isles belong to the species *Avena sativa*, in which there is no sharp division of the tissues connecting the spikelet and the pedicel, and the grain when fully ripe separates from the pedicel by a distinct fracture of the tissues uniting the two.

The wild oat can easily be distinguished from cultivated forms by the strongly grown, twisted and kneed awn, which is invariably present on all the grains of the spikelet. An awn is developed in many varieties of cultivated oats, but then only on the lower floret of the spikelet (Fig. 34).

Avena strigosa, another species, must be mentioned here, for some varieties of this group are the oldest forms known in Britain, and are still cultivated in mountainous districts in Wales and in some of the western districts of Scotland. The grains of all the varieties of *Avena strigosa*, commonly known as the " bristle-pointed " oat, are small, and their attachment to the pedicel is similar to that found in *Avena sativa*. Instead of a more or less indeterminate end to the dorsal palea, however, the tip of the husk is extended into two long, fine, awn-like projections, and each grain of the spikelet carries a well-developed, twisted and kneed awn. The various forms of oats of this species flourish in Wales and Scotland on soils where none of the varieties of *Avena sativa* can be grown with any degree of success. The grain is small, but the straw is long, fine and abundant, and makes good fodder.

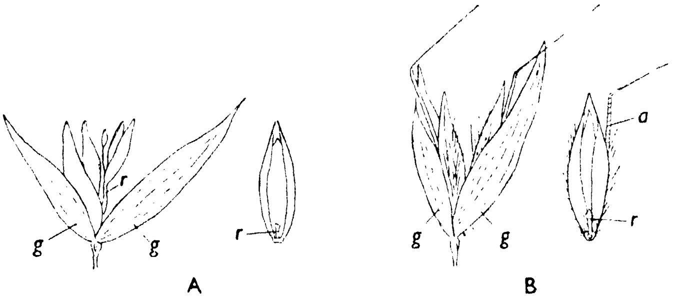


FIG. 34.—SPIKELETS OF CULTIVATED AND WILD OAT.

A. Spikelet and grain of cultivated oat.
B. Spikelet and grain of wild oat.
a, dorsal awn. *g*, glume. *r*, rachilla.

The bulk of the oats grown in this country is used for stock feeding and hence the value of the grain is adjudged from this angle. In barley the coverings of the grains (paleæ) are fused with the kernel (caryopsis) and it is impossible to detach them from the grain when it is dry : even after soaking in water separation can only be effected with difficulty. In wheat, on the other hand, the kernel is separate from the paleæ and may be removed readily on rubbing the ear through the hand. In oats, although the paleæ envelop and effectively protect the caryopsis against the weather, they are not actually attached to it in any way. There is one species of oat, *Avena nuda*, the so-called naked oat, in which the palea open, as in wheat, leaving the kernel free and exposed at maturity.

If the true kernels of wheat and oats are examined chemically the largest differences in composition are found in the quantity of crude fibre and ash, both of which are higher in wheat ; the fat is invariably higher in oats, and the amounts of crude protein are similar in both cereals. But oats when used for stock food are usually consumed unhusked, and hence the composition of the whole grain is of great importance. Comparing wheat and oats on this basis the differences in composition are considerable, but they are centred mainly around the crude fibre, which frequently amounts to as much as 10 per cent of the weight of the whole oat grain—the husk forms 20–30 per cent by weight of the grain and of this about one-third is fibre. After the fibre, the next largest difference is found in the crude fat, which is naturally much lower in the whole grain than in the kernel of oats, but is still higher than that found in wheat. The crude protein also suffers some reduction, whilst the ash is increased.

Varieties. Cultivated oats may be broadly classified into two main groups—winter varieties and spring varieties. Within these groups, however, are further important variations which enable sub-divisions to be made. The colour of the grain, for instance, whilst white in the majority of varieties, may be yellowish, black, brown or grey. Some varieties have short plump grains, others produce a much longer and thinner type ; some have a spreading panicle, others a one-sided panicle giving a banner-like appearance, and a large number have an intermediate type of ear.

It is believed that for several centuries, up to the first half of the 18th century, various forms of naked oat (*Avena nuda*) were extensively cultivated. They were known as Pilcorn or Piley or the Skinless Oat. They did well under relatively poor conditions and were often the last crop grown in systems in which land was cropped for a period and then allowed to go out of cultivation for a rest or recuperative period. During the 18th century a variety called Poland was imported and grown extensively in the South of England : various forms of Dun or Brown oats, and Black oats in the Midlands, replaced the naked varieties. Later in the same century Black Tartarian and White Tartarian oats spread from the east into Europe and subsequently into England. The Black Tartarian became a very popular variety and replaced the other forms of black oats.

In 1788 the famous variety, Potato, was discovered growing as an isolated plant in a Cumbrian potato field ; it was probably introduced from South Europe amongst packing straw. This variety became of importance in the north, and even today the variety, or one of its many selections, is occasionally grown in the north of Scotland. Certain other varieties came into being in a similar way by observant farmers selecting chance occurring plants or useful looking types within existing crops, and multiplying them to produce new varieties. For instance, the variety Sandy originated from an odd plant found growing on ditch cleanings in Aberdeenshire, whilst the varieties Hamilton and Hopetown were pure line selections out of the Potato oats.

Many of the above varieties of oats were grown as much for their straw as for their grain. This particularly applied to the varieties Potato and Sandy and their derivatives, which are referred to as *straw producers*. An outstanding advance in the more predominantly *grain producers* took place in the last twenty years of the 19th century as a result of hybridisation work by Dr. John Garton. He introduced a number of improved varieties, amongst which the most famous was the variety Abundance, marketed in 1892. These varieties had a great effect upon oat growing in the country, and Abundance could still be found in use as late as 1940. Waverley, Yielder, Goldfinder and Bountiful were other successful types produced. The varieties Supreme, Onward and Forward have been successful varieties in more recent times.

The Swedish plant breeding station at Svalöf has contributed a number of successful hybrids to the British farmer in the last 40 years. Victory, Star, Eagle, Sun II and Blenda have all been successful varieties. These oats have all been reasonably strong in the straw, good and reliable yielders, with a high kernel-to-husk ratio in the grain and with average date of ripening.

In the last 30 years the Welsh Plant Breeding Station has produced some important varieties. S.84 was a strong strawed spring oat, rather late in maturing and with only an average yield. S.147 and S.172 were two highly successful winter oats ; the first had a high yield but rather long straw which made it unsuitable for highly fertile soil or for use with high rates of fertiliser ; the second had an extremely short and strong straw but had not the intrinsic yield potential of the former. Powys, a hybrid between S.147 and S.172, to some extent combined the features of the two parents. Its yield potential is actually better than S.147, but the straw strength, whilst good, fails to equal that of its S.172 parent. Each of these winter oats is far superior to the old Grey winter and Black winter varieties they replaced. Another important variety is the spring oat Milford (S.225), a cross between Victory and S.172. It has similar straw characteristics to S.172 and is in a class by itself amongst spring oats for this feature, in the same way as its parent is amongst winter varieties. Again, however, it is not capable of high yields.

An effort has been made at both the Welsh Plant Breeding Station and at the Cambridge Plant Breeding Institute to breed for resistance to Stem Eelworm, not to be confused with Cereal Root Eelworm (see p. 432). The Welsh varieties S.172, Pennant, Milford and Manod, and the Cambridge winter variety, Barnwell, all show this resistance. Breeding for mildew resistance has also received attention, and the Welsh varieties Manod and Penrhyn are outstanding in this respect.

For hill land areas, earliness of maturity is a desirable characteristic. Winter oats are in general early maturing, but are unsuitable for hill conditions. One of the merits of Supreme, mentioned earlier, was its earliness. Ayr Commando and Ayr Everest produced in this country, Primus II from Svalöf, together with Clinton from U.S.A. are all early maturing varieties.

As with wheat and barley, many plant breeders are striving to produce better oat varieties designed to meet modern conditions. An essential feature of this is to combine high yielding potential with extreme straw strength, so that the capacity for yield may be exploited by high fertiliser use without the risk of lodging. The plant breeder has not achieved the same degree of success with oats as with wheat and barley. Straw strength is possessed by the varieties Milford and S.172 but not the capacity for yield. Another feature that requires improvement is loss of grain from the panicle (shattering) when it is left until dead ripe, as is necessary when using the combine harvester.

The current N.I.A.B. list of recommended varieties is given in Appendix V.

Position in Rotation. The position of oats in the crop rotation is by no means so fixed as that of wheat or barley, and it varies greatly with the extent to which other corn crops are cultivated on the farm. In Scotland and in many parts of Northern Ireland where neither wheat nor barley is extensively grown, oats follow roots, leys or, if necessary, oats themselves. A high frequency of oats in the rotation can lead to severe trouble with two eelworm pests : Stem Eelworm and Root Eelworm. The varieties mentioned above have considerable resistance to the stem eelworm, but all varieties seem to be susceptible to Root Eelworm (see page 432). In the predominantly cereal-growing districts of the country the sequence of oats undersown with one-year seeds, or a two-year ley, is useful as a disease break in cropping systems containing a high percentage of wheat and barley.

Manuring. Although the oat crop is more tolerant to conditions of soil acidity than wheat and barley, it is likely to give the best yields on soils approaching neutrality. The crop is, however, very sensitive to manganese deficiency, a condition common on soils where a high organic matter content is associated with a high pH. The condition is known as " grey leaf " or " grey speck " because of the characteristic leaf symptoms. On some of the fen peats this deficiency makes it almost impossible to grow oats. If the condition can be recognised early enough, applications of manganese sulphate at rates of 20 lb. per acre either as a spray or, diluted with a filler, as a dust can control the condition. By the time the characteristic leaf symptoms appear it is too late to effect a full and complete control.

As regards the major plant nutrients the average theoretic optimal rates are approximately the same as those for wheat (see p. 222). Oats, except perhaps S.172 and Milford, have not the straw strength to stand the full optimal rates of 70 units per acre of nitrogen. In most cases applications of 40 units per acre only are used. With phosphate, adjustments for the wetter areas and deficient soils as discussed for wheat (see p. 223) are necessary. With potash the adjustment for the deficient soil only is required. In some rotations oats are taken as the first crop after well-fertilised leys, and in these circumstances the crop is often grown without any fertiliser. The usual economy of phosphate and potash can be effected by combine drilling the fertiliser with the seed. On farms with a high proportion of stock and a low percentage of arable, farmyard manure is often available for the oat crop in which case fertilisers may be omitted. With winter oats the nitrogen is given as a top dressing in the spring as in the case of winter wheat.

Cultivation and Sowing. In the west and the north the crop is mainly spring sown but, in the drier districts of the south and east, there is a greater preference for winter varieties. The winter varieties are less prone to damage from frit fly attacks than the spring varieties (see p. 430). They are also earlier ripening and thus of value in spreading the harvest period. It is important to sow spring oats early in the spring as a protective measure against frit fly attacks ; trouble with this pest may be expected in most areas in crops sown later than the first week in April.

Spring varieties and winter varieties of oats require the typical spring and autumn cereal type of seed-bed respectively (see pp. 224 and 225). Where the crop is taken as the first crop after ley or ploughed-out grass it is advisable to use the disc harrows in the initial stages of preparation of the seed-bed.

The seed sample should be of high germination, plump seeded, free from weed seeds and immature grains. The usual rate of drilling is from 1 to 2 cwt. per acre. Recent summaries of experimental data place the physical optimum seed rate for oats between 2 and 2½ cwt. per acre, which is appreciably higher than that for winter wheat or spring barley. From the same data the economic optimum seed rate where the farmer sows his own seed is 2 cwt. per acre ; when the purchased seed is worth twice and three times the same weight of grain from the crop the economic optima are respectively 1¾ and 1¼ cwt. of seed per acre. There are no equivalent data for winter oats.

It is advisable to dress the seed with an organo-mercurial seed dressing to control seed-borne diseases, and this should be replaced by an insecticidal-fungicidal seed dressing where high populations of wireworm are present. After drilling the seed should be harrowed in and, if necessary, the seed-bed rolled with a Cambridge roller. Where injurious populations of annual weeds develop the appropriate type of herbicide may be used. Greater discretion in choice of herbicide needs to be exercised for oats than for wheat or barley ; for instance MCPA should be used in preference to 2,4D. For further information see Chapter VIII and Appendix VI.

Harvesting. The oat crop is cut at an earlier stage of maturity than either barley or wheat, because oats are liable to shed the grain when fully ripe. Moreover, the grain will ripen satisfactorily in the stook and the straw is of much higher feeding value when cut at this early stage. Thus the crop is cut whilst the straw is still slightly green and before the chaff flies.

The crop is left in the field usually for at least a fortnight—tradition decrees that the stook should be out for three Sundays—and to prevent heating in the stack. In districts of higher rainfall it is usual to make relatively small stacks and to arrange for through ventilation of the stack. Faggots laid out in the middle of the stack are helpful.

The liability to shedding when dead ripe makes the oat crop less suitable for combine harvesting than wheat or barley. In addition a dead ripe straw is less palatable and of lower feeding value for stock. Nevertheless, great economy in the man hours needed to harvest the crop can be gained using the combine harvester technique. The standard man hours per acre for producing and binder harvesting the crop are taken as 29 whereas the equivalent figure, using the combine harvester, is 15. An increasing proportion of the crop is now being harvested in this way.

Yield. In common with the other cereal crops oats have shown increasing yield trends in recent years. The official average figures show that whereas the pre-war yields averaged 15·8 cwt. per acre, subsequent five-year averages are as follows : 1940–44, 16·7 cwt. ; 1945–49, 17·1 cwt. ; 1950–54, 19·3 cwt. ; 1955–59, 20·3 cwt. per acre. The yield increases have not been as great as those with wheat and barley over the same period. Crops of 35–40 cwt. per acre are not uncommon on good land in good seasons, and yields of over 2 tons per acre have been recorded.

Straw yields tend to be about one-third greater than grain yields under most conditions. Grain to straw ratios are greater in dry areas than in wet areas ; they are also influenced by variety and quantity of fertiliser used. High nitrogen levels decrease grain-to-straw ratios.

RYE

Rye as a grain crop is of very minor importance in this country, its cultivation being confined mainly to very poor light land where the other cereals would not prove remunerative. The public taste for " crisp bread " has in recent years tended to extend the cultivation of the crop, and during the food production campaign of 1939–45 the crop received a mild fillip.

The crop bears a strong likeness to the other cereals botanically, but has additional features of agricultural value (Fig. 30). It is, for instance, the hardiest of all the cereals and can over-winter under conditions of low temperature to which even wheat will succumb. It does well on sand and light peat soils under conditions of considerable soil acidity, and its rapid germination and quick establishment make it a useful forage catch crop.

The grain is similar in composition to wheat and may be used for stock feeding under comparable conditions, but the plant is used chiefly as a fodder crop for sheep. Sown in the early autumn it makes abundant growth before the end of the year, and by the succeeding February furnishes a good bite for lambing ewes. This early bite can also be used to good advantage for the dairy herd, for it provides an invaluable stimulus to milk production by affording a change of diet from the monotony of the winter feeding programme. Provided the sheep and cows are not kept on the crop too long, rye re-establishes its growth rapidly and will then produce a fair yield of grain. Frequently, however, it is ploughed in after folding, and the land is left in that condition until it is time to prepare it for roots. On light land this method of dealing with the crop is an excellent preparation for roots.

Varieties. Very little work has been done on the problem of varieties of rye. Rye, unlike the other cereals, is cross-fertile, and is therefore more difficult to maintain in a pure condition. It exists in two more or less distinct forms, winter rye and spring rye. It is inadvisable to sow winter rye too late in spring, for there is then a danger of an almost complete failure through the non-production of stems and ears.

Certain continental varieties of winter rye are available, including King II, Steel, Pearl and Petkus. These have shorter, denser ears, and shorter straw, than the older types. Stocks of genuine spring rye are not plentiful.

Position in Rotation. Where rye is grown it usually replaces the other cereals in the rotation.

Manuring. Although rye will succeed on poor acid land this is not to say that much better results will not be obtained when the crop is suitably fed. Applications of lime, phosphate and potash give remunerative returns when applied in appropriate quantities. Care must be taken in the application of nitrogenous fertilisers lest excessive growth is induced and lodging follows : top dressings for grain production should be made in late spring.

Cultivation and Sowing. The preparation of the seed-bed follows the lines already indicated for cereal crops.

The usual rate of seeding varies from 1 cwt. per acre in early autumn to 1½ cwt. per acre for winter and spring sowings. The seed of winter varieties should be drilled in September or early October and of spring varieties in February to early March. The seed is drilled, harrowed in and rolled as with other cereal crops. Little or no subsequent cultivation is given to the crop.

Harvesting. Rye is the first of the cereal crops to ripen and cutting takes place when the straw is dead ripe. Thus little fielding is necessary.

Yield. The national average yield of rye in the five-year period 1950–54 was 18·2 cwt. and from 1955–59, 19·7 cwt. per acre. It is thus a lower yielding cereal crop than the others mentioned above. These yields were obtained from soils which were much poorer than those from which the wheat, barley and oat yields were obtained. Straw yields from such crops will be of the order of 30–40 cwt. per

PULSE CROPS

Certain leguminous plants which are cultivated mainly for their seed are called pulse crops. In this country the only pulse crops are beans and peas ; vetches are not usually included because as often as not they are grown for cutting in the green state and not for the seed. Sometimes these pulse crops are called "black" straw crops, to distinguish them from "white" straw crops, which are the cereals.

Pulse crops owe their importance largely to the nitrogen present in the seed. Beans, for instance, contain double the quantity of protein found in wheat and oats, and almost three times the quantity found in barley. This protein does not result from the extra liberal use of nitrogenous manures, but is due to the ability, shared by all members of the Leguminosæ, of the plant to make use of the free nitrogen of the air through the medium of bacteria which inhabit the nodular swellings on the roots (see p. 396). Not only the seeds but all parts of leguminous plants are relatively rich in nitrogen. When the roots of these plants decay the soil is enriched with nitrogen which becomes available to the next crop. This is the main reason why beans, or a clover ley, are recognised as a good preparation for a cereal like wheat.

BEANS

Beans are distinguished from the clovers, vetches and peas principally by the square, hollow stems which vary in length with the variety. The leaves are pinnate, and usually consist of two, four or six leaflets, but the petiole or stalk of the leaf instead of terminating in a tendril, as in vetches and peas, ends in a short, very much reduced leaflet. The flowers arise as short racemes in the axils of the leaves (Fig. 35).

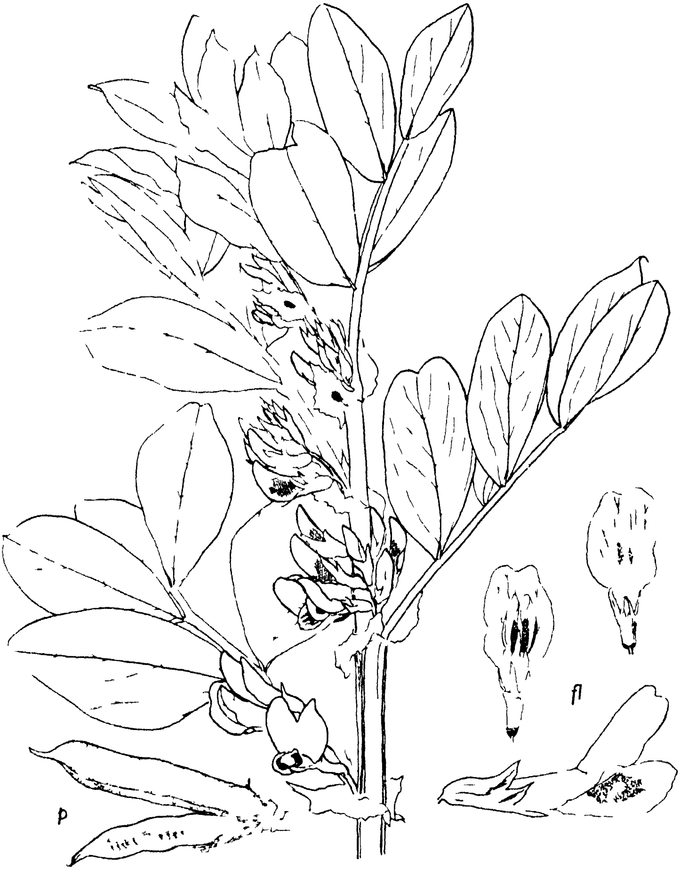


Fig. 35.—Field Bean (*Vicia vulgaris*).
fl, detail of flower. *p*, pods

Up to the time of ripening the pods are soft and green, with a soft, white, woolly lining. On ripening they dry up considerably, become black and much tougher, the soft lining disappears, and if left until completely dry the pods eventually split along both the upper and the lower lines of division, and the seeds are ejected.

The bean is characterised by a strongly developed tap-root which is capable of penetrating to considerable depths and eventually when ploughed in of adding large amounts of organic matter to the soil.

Varieties. Beans are classified into two main groups, winter beans and spring beans. The former are sown in the autumn and are hardy and able to withstand the cold of a moderately severe winter, though they may be killed during spells of exceptionally severe weather, especially if the land is wet from want of drainage. Winter beans develop more secondary stems and usually produce a fuller crop than do spring varieties. They are also less subject to attacks of black aphis which do not, as a rule, appear until June, by which time an early sown crop of winter beans may escape serious injury (see p. 433). They are, on the other hand, more susceptible to the fungus disease known as Chocolate spot which, in some years, causes severe loss of yield.

There are three main forms of spring beans ; *Tick beans* are small, round or flat-oval seeded types with a 1,000 corn weight of 10–20 oz. ; *Horse beans* are larger seeded, flat-oval in shape, with a 1000 corn weight of 20–30 oz. ; the *Large Seeded beans* are flat-oval with a 1000 corn weight over 30 oz. Tick beans may be grown as a cash crop for the pigeon trade ; the others are used for farm stock. Horse beans, and even more so the Large Seeded beans, are earlier and shorter strawed than the Tick beans. Some of the larger seeded types are related to horticultural broad beans.

Beans are a crop that are partly cross-pollinated and, unless a stock is grown in isolation, admixture can occur. Up to recently the variety situation had got into a thoroughly unsatisfactory state. In the last few years the N.I.A.B. have examined some 510 stocks, 110 of them in full field trials. As a result of this work they have listed two useful varieties of winter beans, six varieties of tick bean, two varieties of horse beans and two varieties of the large seeded beans (see Appendix V). It is evident that there is room for considerable research by plant breeders on the bean crop.

Position in Rotation. On heavy land beans are sometimes taken as a cleaning crop in the place of roots, and the success of the crop may then be taken as a test of skill in cultivating clay land. In some rotations they replace the clover break, and in those districts where the three-course system including a bare fallow was practised, beans followed wheat after fallow. Often beans may precede wheat.

Manuring. To grow beans well, a soil whether heavy or light must contain a plentiful supply of lime. Being a leguminous plant and thus able to obtain supplies of nitrogen from the air, the crop does not as a rule need nitrogenous fertiliser. Most growers believe in the value of farmyard manure and experimental work confirms that substantial responses are usually obtained to a 10 tons per acre dressing.

Use of fertilisers is not based upon such comprehensive experimental information as in the case of the cereal crops. In the past high rates of phosphatic and moderate rates of potash fertilisers have been used ; 70–80 units of phosphoric acid plus 50–60 units of potash in addition to F.Y.M. are examples of fertiliser practice formerly recommended. It is known that the crop is exceedingly sensitive to a low soil potash status, the plants becoming stunted, showing a typical black scorch on the margins of the leaves, and giving very low yields. Most of the experimental work has shown greater responses to potassic and less to phosphatic manuring on ordinary soils. The response to potash is considerably reduced where F.Y.M. is used. The bean crop is liable to give unsatisfactory germination if seed and fertiliser are placed in direct contact, as occurs with ordinary combine drilling. On the other hand greater responses to both phosphate and potash are obtained where the fertiliser is placed in a band 2 in. to the side and 3 in. below the seed than with broadcast application. A 3–5 cwt. dressing of a 0 : 10 : 20 or similar compound is probably the most satisfactory fertiliser for the crop, particularly where a placement drill is used.

Cultivations and Sowing. Beans require a deep but not necessarily a very fine seed-bed, and unless the clods are so large that they prevent the seedlings piercing through to the light a rough surface is not harmful ; in fact, with winter beans it is often desirable, since it provides some shelter for the young, tender plants, during the winter.

After wheat on heavy land, or barley on the medium loams, the dung is applied as soon after harvest as possible and ploughed in. After the furrows have been harrowed to a rough seed-bed and the fertilisers applied the beans are drilled and covered by harrowing. A distance of 12 in. or more is allowed between the rows to facilitate steerage hoeing and weeding and often the rows will be spaced as much as 18–27 in. apart. A good distance between the drills and between the plants in the drill is essential to prevent too great a vegetative development, in which case the plants fruit sparsely.

The seed rate varies from 1½ to 2¼ cwt. per acre : as with the cereal crops there is a definite physical optimum seed rate. The optimum seed rate varies with environmental conditions and there is evidence to suggest that it is at a higher seed rate on the more fertile soils. There is insufficient experimental evidence to draw reliable conclusions concerning the economic optimum seed rate. The sowing of winter beans should be completed in October if possible, spring beans being sown during March.

In the north of England it was formerly a practice to ridge the land in the same way as for turnips, the ridges being 24 in. apart. Farmyard manure and the fertilisers were put in the ridges and the seed was either sown broadcast before, or drilled after, splitting the ridges. Another method of sowing, particularly winter beans, was by fitting a small seed hopper or drill on the plough beam in such a way as to sow down each second or third furrow opening, the seed being covered by the turning furrow. The spring sown crop is usually drilled.

Post-drilling Cultivations. Where beans are sown in rows of appropriate width inter-row cultivations as cleaning operations can be carried out. Recent trends are to use suitable herbicides for the crop. DNBP or Dinoseb may be used as a selective herbicide, or another technique is to apply Simazine as a pre-emergence weed killer.

Harvesting. Beans should be cut when the leaf has fallen, at which time the hilum or scar, or point of attachment of the bean to the pod, will be black. It is usual to cut and tie the crop with a binder, but the knife must be kept sharp and the canvasses should be old ones since the strong haulm of the crops wears them out quickly. The sheaves are stooked in fours and should remain in the field until perfectly dry. A little outside moisture is not detrimental, for the stack is open and the wind can blow through. The stack should be thatched immediately, because beans cannot shed the rain-water as can wheat or rye. It is unusual to thresh beans until they have been in the stack at least four months, and it is better to allow a stack to stand over the summer if possible because new beans are not suitable for feeding.

The bean crop can be harvested direct with a combine harvester provided it is dead ripe. Under these circumstances, however, considerable shedding of the seed is liable to occur before the crop is cut. There is a considerable need for a variety of beans having pods resistant to shattering when dead ripe so that the labour saving of combine harvesting may be obtained.

The straw is quite useful for feeding and is usually given to stock to pick over. The upper part of the plant is very palatable but the fibrous portions are generally discarded by the stock.

Yield. The average yield of the bean crop over the last seventy years has been 15·7 cwt. per acre and during the last 20–30 years there has been a slightly downward trend. Since records have been kept the yields have fluctuated violently from one year to another with often 100 per cent differences between successive seasons. In good seasons yields of over 30 cwt. per acre quite frequently occur. Straw yields are 25–30 cwt. per acre.

PEAS

The largest acreage of peas is found in the east and south-eastern counties of England, where the relatively dry summer and autumn are favourable for growing and harvesting the crop. The stem of the plant is squarish and generally hollow, as in the bean, but it differs from that plant in its trailing habit. At the base of the leaf are two large, fleshy stipules, in some cases much larger than the leaflets themselves. The leaves are compound with one, two or more pairs of leaflets placed opposite to each other on the leaf-stalk, which is finally extended to form a series of tendrils, these being in reality leaves modified into thread-like structures ; the tendrils are able to attach themselves to any object they may touch, thus acting as supports for the weak succulent stem (Fig. 36). The straw length varies considerably between varieties, from one foot to over five feet in length.

The flowers arise on stalks varying in length with the variety ; the stalks bear one, two or more flowers, the number again being a varietal characteristic. The flowers are papilionaceous and the fruits, again two-valved pods, contain a varying number of seeds. As in the case of many other plants of the family, the fruits when fully ripe open by a violent fracture of the two halves of the pod, which twist on themselves and in so doing eject the seeds.

Varieties. Peas are grown on a farm scale for stock food, for drying, or for picking green for immediate sale, for canning or for quick freeze. The cultivation and management for these three purposes are almost identical and the variety used depends upon the purpose for which the crop is grown.

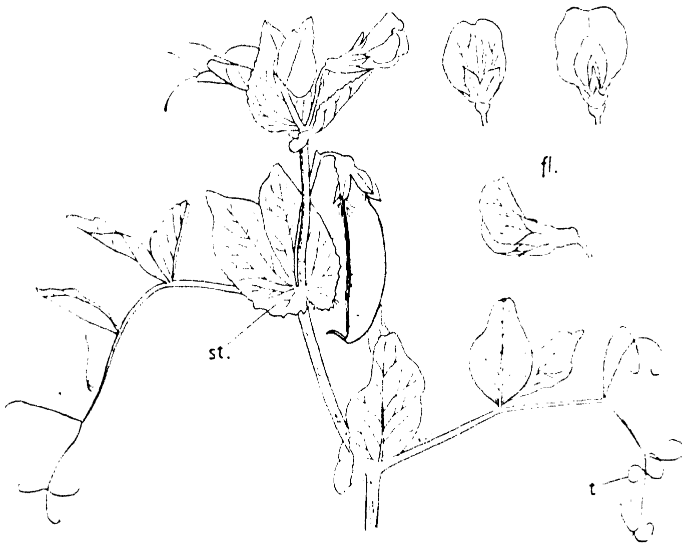


FIG. 36.—FIELD PEA (*Pisum arvense*).
fl., detail of flower. *st.*, stipule. *t*, tendril.

Varieties of peas commonly sown may be grouped as follows :

For stock feed : Grey or Dun, Maple, Partridge, Black-eyed Susan.
For drying : Harrison's Glory, Lincoln Small Blue, Zelka, Rondo, Big Ben, Servo.
For picking green : The Lincoln, Alderman, Thomas Laxton, Onward, Early Bird, British Lion, etc.

Grey or Dun peas exhibit considerable variation within the group in so far as length of straw, time of ripening and size of pod are concerned. The grain, as the name implies, is grey in colour and the flower is purple.

Maple peas have speckled markings and are sometimes known as " Pigeon " peas because of their suitability for feeding these birds. The earliest ripening Maples are known as " Partridge " peas, whilst Black-eyed Susan, a variety widely grown in the eastern counties, has grain which is dun coloured or brown with a black eye. There is little to choose between these varieties and the selection should be made according to experience in any particular area.

Pea varieties used for drying are similar in general appearance to garden varieties. Prussian Blue is a variety with small round bluish-green seeds and has a very long straw. It is rarely grown at the present time. Servo and Rondo are short-strawed varieties with large round bluish-green seeds. They are higher yielding and easier to harvest than Prussian Blues. Harrison's Glory and Zelka are "marrow-fat" types; that is to say, they have large dimpled seeds which have usually a better saleability than the "round blue" types. Both varieties are short strawed and Zelka is the better yielder.

The choice of peas for picking green is very extensive and the names given are simply those of very popular sorts, all of which are garden peas as distinct from field peas. A good variety for this purpose must not only give a high yield of well-filled pods per acre, but in addition the pods must retain their freshness when bagged for market; they must be easy to shell and resistant to mildew. Special characteristics are needed for varieties intended for canning or deep freeze. These are usually grown on contract, and the contracting firm supplies the seed of the varieties they require.

Position in Rotation. Threshing peas as a cash crop are usually grown on the heavier textured soils of high fertility in the drier climate of the east of England. In the rotations followed in these areas peas usually are taken between two cereal crops. In some cases they may follow a cereal crop and precede potatoes in place of the clover seeds in popular crop sequence—seeds, potatoes, wheat—of the warp and silt soils. Green peas are grown on a wider range of soils usually near the main centres of population. The fodder types of peas are not grown commonly and then only on the lighter types of soil. Again they usually occur between two cereal crops. Where peas are grown frequently on the same land severe trouble may be encountered with Pea Root Eelworm (see p. 438). Pea and Bean Weevils and Pea Moth also tend to be troublesome pests in the main pea-growing areas.

Manuring. Peas, like most leguminous crops, are very intolerant of soil acidity. The root nodule organisms usually supply all the nitrogen the crop requires and applied fertiliser nitrogen is as likely to depress yield as to increase it. Traditional fertiliser use for the crop was relatively high rates of phosphate and moderate rates of potash, as, for example, 72 units of P_2O_5 and 50–60 units of potash per acre. Recently fairly comprehensive fertiliser trials have shown the crop to be relatively unresponsive to phosphatic fertilisers but much more responsive to potash on most soils. Fertiliser placement trials where the fertiliser was drilled 3 in. below and 2 in. to the side of the seed have given much better response than broadcast applications. In common with beans, the germination of the seed is liable to be severely damaged by direct contact placement of seed and fertiliser such as is obtained by ordinary combine drilling. The experimental work suggests that 40–80 units per acre of potash, applied where possible with a special placement drill, would be ideal for the crop on most soils. Since straight potash fertilisers are not too easy to handle a 0 : 10 : 20 or similar compound is to be preferred. Where the soil is *acutely* deficient in phosphate, up to 54 units of P_2O_5 may be required. On some soils maximum yields of peas may be obtained without any added fertiliser.

Cultivation and Sowing. The cultural operations are simple and consist of early ploughing of the stubbles in the autumn and a good cultivating as early in the New Year as possible, aiming at keeping the frost mould on the surface. Drilling is carried out from the end of January to early April, dependent upon suitable conditions for seed-bed preparation and the type of peas being grown. Experiments with threshing peas have shown that earlier drilling (in this case early March) gives better crop yields. With the earlier drillings, however, the use of organo-mercurial or, better still, TMTD seed dressings are particularly necessary in order to protect the seed from the fungal rots liable to occur when a cold wet spell follows drilling. With the green pea crop a much wider range of drilling dates is used. To catch the early market, early varieties such as British Lion, are sometimes sown as early as December. Late April and May drillings using later maturing varieties are also practised, as the very late green pea market may be remunerative.

The seed-bed required is similar to that required for spring-sown cereals. With very early drilling it is not advisable to work it down too fine otherwise capping may result. Drilling the seed about 2 in. deep and at a rate of 2 cwt. per acre is the normal practice. Experimental work has confirmed that 2 cwt. per acre is both the physical optimum and the economic optimum, except where the seed costs three times that of the same weight of crop. The row spacing may vary from the ordinary 7-in. drill spacing to 14 or 21 in. attained by stopping alternate, or two coulters out of three, respectively. A 14 in. spacing is probably ideal as it gives a well-spaced plant population, and at the same time allows steerage hoeing to be done.

Post-drilling Cultivations. Peas should be harrowed just as the shoot begins to peep above the ground. If used at this time the harrow destroys many small weeds without hurting many of the pea plants. The crop should be harrowed and rolled when about 3 in. high, and inter-row cultivations should be continued until the rows meet and the hoes can no longer be worked. The limited time available for this operation makes a clean soil a very necessary condition of pea cultivation, and accounts for the fact that the pea crop is regarded as one of the worst weed-promoting crops we have. In recent years the selective herbicides, Dinoseb and MCPB have been used extensively for weed control in the crop (see Appendix VI).

Harvesting. When the crop is required for grain it should not be allowed to ripen before being cut or many of the pods burst, and the peas fall out during the turnings to which it is necessary to subject them whilst drying in the field. It is sufficient that the haulm should be yellow, and the pods tough and of the same colour. The crop is usually cut with a mowing machine which may be fitted with extensions (" pea-lifters ") to the fingers of the cutter bar. Special pea cutters with better performance than the ordinary mower are also in use in the main pea-growing areas. After cutting the crop is windrowed and turned, either by hand or by side delivery rake type of swath turner until it is completely dry. An alternative procedure is to let it dry partially in the windrow and then complete the process on tripods or tetrapods. In the latter case the crop is protected from the worst effects of wet harvest conditions in which severe losses occur due to shedding and lowered quality due to discoloration.

After drying out thoroughly peas in windrows may be harvested with a combine harvester fitted with pick-up attachments, or they may be carted, stacked and subsequently threshed. Peas on tripods or tetrapods may be swept to a stack by means of buckrakes, combines may be taken from tripod to tripod and the crop forked on to the cutter bar table, or, the more labour-absorbing method of forking from tripod to trailer, stacking and subsequently threshing may be employed.

Finally, peas should be stacked when perfectly fit, and not before, in long, narrow stacks in a position which exposes them to the maximum amount of wind. When carted in doubtful condition it is advisable to stack on wooden frames or tripods, or to adopt other means to permit free circulation of air through the body of the stack. When threshing, it is necessary to set the drum correctly because split peas are useless for seed purposes or for canning. Pea haulm is extremely valuable as winter fodder.

Peas are picked green for human consumption, usually by gang labour on contract at a fixed price per 40-lb. bag. Good judgment is necessary to determine the correct stage of the crop when picking should begin. Flat pods give rise to loss of crop whilst over-mature pods are equally unsaleable. The general procedure is for the pickers to pull the haulm as they go and strip off all the pods.

The green crop intended for canning or quick freeze is usually cut green, collected immediately and sent to a vining machine. Here the pods are stripped off and the green haulm which is left then becomes a useful by-product for silage making. The whole operation between cutting and processing needs to be carried out in the minimum time if quality is to be retained. Location of the processing factory thus, to a large extent, determines the areas where peas of this type are grown. This type of crop must also be harvested at exactly the right state of maturity, that is to say, when the seeds are a reasonable size but are tender and retain sufficient sugar to impart the sweet taste. The processing factories make graded payments according to quality, which is determined by tenderometer and, sometimes, sugar tests.

Yield. The average yield of grain is 17 cwt. per acre with 20–25 cwt. per acre of straw. An average crop of green peas yields as first earlies 70 bags, second earlies 120 and main crops 150 bags (40 lb.) to the acre.

Chapter X

THE CULTIVATION OF ROOT, FORAGE AND MISCELLANEOUS CROPS

ROOT CROPS

ALTHOUGH potatoes are often referred to as root crops and have been thus classified in this chapter, they are botanically distinct. The true root crops are those whose principal edible portion is the true root plus a certain amount of what the botanist calls the hypocotyl, which is a transitional structure intermediate between root and shoot. All the true root crops are biennial in habit. As usually grown they spend the first season of growth in developing the root, whose store of food they would normally exhaust the following season in producing stem, flower and seed.

The chief food reserve of the common farm roots is sugar, though the cellulose and other non-woody portions also serve as food materials to ruminant animals. In addition, the " tops " (i.e. the foliage) of the plants is a valuable fodder except in mangels and carrots.

With the exception of the kales and similar crops grown as folded crops, the acreage of fodder root crops has declined steadily in this century. In the 1870's the combined area of turnips, swedes and mangels grown was more than 2,000,000 acres ; by 1939 this had declined to 606,000 and by 1958 to 376,000 acres. By contrast the combined acreage of kale, cabbage, savoy, kohl rabi and rape was 176,000 acres in the 1870's, 194,000 in 1939 and by 1958 had reached 458,000 acres. The reason for these changes is the increased cost of labour during the period which has made the true fodder root crops a relatively expensive source of starch equivalent (i.e. some 50 per cent more per ton of S.E.) than that in the form of hay or silage ; the folded forms of the leafy fodder crops on the other hand can produce starch equivalent at about the same cost as conserved grass products.

Parallel to the decrease in the fodder root crops has been an increase in the cash root crops. Sugar beet was only introduced as a farm crop in the 1920's and the acreage of potatoes grown has also increased to some extent. The combined acreage of these crops in the 1870's was 443,000 acres ; by 1939 it had increased to 791,000 acres and by 1958 it had reached 998,000 acres.

The root crops traditionally have been regarded as the principal cleaning crop on the farm. This reputation was based chiefly upon the turnip and swede crop which, being late sown, permitted pre-sowing cleaning operations as well as inter-row cultivations. Where early sown root crops are grown the pre-sowing weed control needs to be done in the autumn. Farm mechanisation makes autumn cleaning a more practical proposition than formerly. The modern trend of thought is that cash root crops are too valuable and too costly to produce for them to be sown on weedy land. This particularly applies to crops like sugar beet and carrots where starting with clean land benefits yield and has a considerable effect upon the costs of production.

THE POTATO

Doubt exists as to the exact date when the potato was introduced into this country, but there is ample evidence to place the period towards the close of the sixteenth century. It was cultivated in Chile and Peru for hundreds of years before it was grown in Europe, and the date of its introduction to the Continent synchronises with the activities of the Spanish discoverers and conquerors of that portion of South America. We are probably indebted to the same agency for the initial distribution of the potato in North America and in Europe. Two sixteenth-century potatoes have been described, one in *Gerard's Herbal*, 1597, and the other by Clusius (*Rariorum Plantaram Historia*, 1601). Gerard's potato was a white-skinned, round type, while Clusius' was reddish-purple and long.

The United Kingdom pre-war acreage of potatoes averaged about 0·7 million acres ; during the war this increased to 1·4 million acres, and by 1959 it had decreased once again to about 0·8 million acres. With an average yield of approximately 7¾ tons per acre the crop becomes one of the most important cash crops grown in the country.

Varieties. The potato is usually propagated vegetatively by means of a tuber or swollen underground stem, and because of this the character of the original plant may be reproduced, without alteration, for many generations. Sometimes, however, changes capable of transmission do occur in one or more portions of the plant and may give rise to a new variety. This is one of the ways in which new varieties have arisen. Most new varieties, however, are produced from seedlings. Many varieties of potatoes are capable of forming true seed, and the potato flower, although self-fertile, is capable also of being fertilised by pollen of other varieties. In practice it is found that whether self- or cross-fertilisation takes place, the seedlings produced from the large number of seeds of even a single potato fruit or " apple " exhibit an extraordinary diversity.

The whole history of the potato in this and other countries is a long story of struggle with various diseases, with the result that plant breeders have frequently had in the forefront of their work the desirability of producing resistant varieties : yield and earliness of ripening are also factors of prime commercial importance. The series of attacks of potato blight (*Phytophthora infestans*) which swept over the British Isles from 1845 to 1847 acted as a great stimulus to breeding disease-resistant varieties, whilst in more recent times Wart disease (*Synchytrium endobioticum*) has resulted in the introduction of many new varieties capable of resisting the fungus responsible for the disease (see Chapter XIII).

In practice potato varieties are divided into three groups ; (i) First Earlies, (ii) Second Earlies, (iii) Maincrops. The first earlies are harvested as soon as, in the judgment of the grower, they have produced a yield which at the prevailing price will give a satisfactory profit margin. As prices are high in the earliest part of the season it is essential to obtain this moderate yield (say 5 tons per acre) as early as possible. Thus a good early variety is one which " bulks up " early : because the crop is lifted before it has completed its growth, yield at maturity is of secondary importance. The early " bulking up " of these varieties is due to their ability to start the formation of tubers under conditions of shorter day length than main crop varieties. As a result of this character some U.K. early varieties are used as main crops in lower latitude countries. Most early varieties are susceptible to tuber rots during winter and this can cause seed storage difficulties.

The second earlies are heavier croppers than the first earlies and should have better cooking quality. One first early variety, Arran Pilot, has, in addition to early bulking characteristics, a heavy mature yield of reasonable cooking quality ; it is therefore a useful dual purpose variety.

In general, all main crop varieties are characterised by their later maturity, heavier cropping capacity and better cooking and keeping qualities in comparison with varieties in the other two groups. The British market has a preference for the white-fleshed types ; by contrast the American market prefers the yellow-fleshed varieties. The mealy textured potatoes are considered to be the best cooking types ; the " waxy " textured varieties are preferred for chipping because they absorb less of the cooking oils. Blight resistance is a much more important characteristic in the main crop varieties than in the other two groups as a result of the time of the year when this disease occurs.

Briefly the history of potato variety development can be summarised as follows. The severe potato blight attacks of the 1840's resulted in the loss of many varieties. In the re-establishment of the industry four varieties played an important part. These were Paterson's Victoria (produced in 1826), Nicoll's Champion (produced 1865), Clark's Magnum Bonum (produced 1876) and Findlay's Up-to-Date (produced 1886) ; each showed some degree of blight resistance and other desirable agronomic characteristics.

During the latter part of the nineteenth century and the first two decades of this century many varieties were raised and marketed. In addition many stocks of individual varieties were given different names. The situation became so chaotic that by 1922 out of 1011 named varieties there were only 452 distinct types ; the variety Up-to-Date, for example, appeared under 152 different names. Intensive work on potato synonyms by the Scottish Board of Agriculture and by the N.I.A.B. clarified the situation. This period nevertheless saw some important introductions. The increasing importance of the early potato market led to the development of several first early varieties, the most important of which were Epicure, Sharpe's Express, Eclipse and Duke of York. Some of these are still grown on a limited scale. Of several second early varieties Great Scot was the most important and is still grown to some extent. Amongst the main crop varieties produced during the period mention must be made of Majestic (produced in 1911) and King Edward VII (produced in 1902), which still dominate the market ; of Golden Wonder, which though a poor yielder is still regarded as the supreme variety for cooking quality ; and Kerrs Pink which has both good yielding and good cooking propensities.

The early part of this century also saw the serious development of potato wart disease soil infestations. It was found that some of the existing varieties showed immunity to the disease. Eventually the disease was scheduled as a notifiable disease by the Ministry of Agriculture. Under the regulations only immune varieties were permitted in the scheduled areas. Since that time it has been necessary to breed for this immunity in the production of new varieties, and this attribute is required before a new variety can appear on the recommended list of the N.I.A.B.

During the late 1920's and early 1930's the Empire potato collection was established at Cambridge. This included a number of potato species other than *Solanum tuberosum*, to which all our existing varieties belong. Some of these species show features such as blight immunity, virus resistance, eelworm resistance, frost resistance, and tuberisation reactions to differing day length, which make them a valuable source of genetical material for breeding programmes. As their chromosome numbers differ from existing varieties, preliminary work on the production of suitable polypoids has to be undertaken before hybridisation can be carried out. Intensive work on these lines is at present in progress at the official plant breeding stations in England, Scotland and Ireland.

The present list of recommended varieties, including a brief description of each, is given in Appendix V.

Position in Rotation. Potatoes are of especial importance in certain counties, as for instance parts of Yorkshire, Lincolnshire, Cheshire, Cornwall, Ayrshire, Norfolk, and parts of Scotland and Ireland. They are grown where soil and climatic conditions are suitable for the production of large yields of high-quality tubers and where the cost of production by virtue of congenial conditions for cultivation and harvesting is not excessively high.

Potatoes flourish best on deep, loose, friable soils, especially when these contain a fair amount of sand and organic matter. On the other hand, poor sandy soils if heavily manured will grow good crops provided the rainfall is adequate ; even heavy clays, if suitably treated, may be made to grow potatoes successfully. Some of the choicest potatoes are raised on the Old Red Sandstone, the marls and sands of the Trias and certain limestone soils ; those grown on the Greensands, Silts and Warp soils are generally of good quality whilst the rich black fens yield immense crops which suffer somewhat in cooking quality. Big crops are grown on recently broken up grassland or young leys, for the tubers revel in the mass of decaying vegetable matter found under such conditions. Under these circumstances wireworm may ruin the saleability of the crop, and a suitable insecticide incorporated in the fertiliser, or applied in other ways, is a satisfactory control.

If potatoes are grown too frequently in rotations a high population of Potato Root Eelworm (*Heterodera rostochiensis*) may be built up (see p. 439). This will reduce yields to very low levels and a long period (up to 10 years) may be needed before the population is reduced to safe dimensions. As most commercial soils are infected it is necessary to limit the frequency of cropping ; experience on various soils suggests that they should not be grown more frequently than once in four or once in five years. A high eelworm population is such a serious matter that it is advisable to err on the side of safety. Even the frequencies mentioned above are only just safe and a single instance of cross-cropping can lead to trouble. With first early potatoes the crop has completed its growth before most of the eelworms have reached maturity : in consequence the population build up is much slower and does not reach such high levels.

The potato crop occupies part of the root break in many rotations ; in others it is the only root crop grown. The old silt and warp land sequence of seeds—potatoes—wheat has in recent years been incorporated into many rotations in eastern England. This sequence facilitates the autumn application of F.Y.M. to the crop, allows the aftermath growth of clover to be ploughed in and permits early ploughing.

Manuring. In view of its liking for organic matter the crop frequently follows peas, beans, or clover seeds. Often in potato-growing districts the seeds' aftermath is ploughed in during the autumn in preparation for the following potato crop. Farmyard manure forms the basis of manuring on most soils. The traditional practice was to apply the dung in the row in the spring and plant the tubers on top of it. In recent years, however, this practice has been replaced on a widespread scale in favour of applying the dung in the autumn and ploughing it in. The advantage of this procedure is a considerable saving of labour and an easing of the pressure of spring work. The rate of F.Y.M. dressing is usually 10 tons per acre or thereabouts.

Whether or not dung is used the potato crop will respond to heavy fertiliser dressings. In 1941 Crowther and Yates summarised all the available fertiliser experiments carried out since 1900. Using prices received for the crop and costs of the fertilisers in recent years, they suggested that the average optimal dressing would be N, 100 units/acre, P_2O_5, 100 units/acre, K_2O, 150 units/acre. On soils where rotations containing a high proportion of cash root crops (i.e. 2 cash root crops in a 5-course or a 7-course rotation) have been the rule, recent experimental work has disclosed a build-up of P_2O_5 to a point where the average optimal dressing is 50 units instead of 100 units of this component of the fertilisers. It would be safer to make this reduction only where the results of soil analysis confirm the higher expected average soil status of P_2O_5. The fen peat soils contain more nitrogen than ordinary soils ; as a result the optimal dressing of nitrogen is below that for the average mineral soil ; a reduction from 100 units to 50 units is appropriate in these circumstances. This reduction does not necessarily apply to peats which were originally acid bog peats. Where potatoes are grown on chalk or limestone soils it may be necessary to increase the potash dressing to 180 to 200 units.

The fertiliser rates given above apply where no F.Y.M. is used ; where 10 tons per acre of F.Y.M. are applied the rates may be reduced by about one-third, although there is some controversy as to whether this should apply to the nitrogen component of the fertilisers. On the soils of very high productive potential farmers often use fertiliser rates greater than those quoted above.

To obtain the greatest efficiency from the fertilisers applied they need to be placed correctly in relation to the seed. Where the land is ridged before planting the fertiliser should be broadcast over the ridge immediately prior to planting. The practice of using deflector plates on the broadcasting drills to concentrate the fertilisers in the bottom of the furrows can check sprouting of the tuber in a dry season. A baulk of timber dragged behind the drill at right angles to the ridges, will pull down sufficient soil to cover the fertiliser and so minimise any damage to sprouting. Where crops are planted by machine without previous ridging, the fertiliser should be placed 2 in. to the side and 1 in. below the seed by means of a fertiliser attachment. Application of fertiliser in solution is beginning to be used in this country ; simple injection equipment using liquid fertiliser facilitates correct placement.

Excessive application of fertilisers can reduce the dry matter percentage in the tuber and so reduce cooking quality. Potash applied in the form of sulphate is rather better than muriate for tuber quality.

Cultivation and Planting. At the present time the potato crop is almost invariably grown on the ridge system. In former times potatoes have been grown on the flat or in beds separated by shallow trenches. The Lazy-bed system was a method of growing potatoes on old grassland, on ley or on reclaimed peatland, formerly used in Ireland and N.W. Scotland. Ridge planting offers three substantial advantages ; it facilitates mechanical weed control, it minimises tuber exposure with the consequential greening and liability to blight infection, and it eases harvesting operations. In the preparation of the seed-bed a primary objective is the attainment of a deep loose tilth from which the ridges may be formed. With the increasing popularity of elevator diggers and complete harvesters it is necessary that the tilth should be as clod-free as possible. Creation of new clods by subsequent cultivations should be avoided.

Two old-established techniques of seed-bed preparation exist and are used on different soils. On the light loamy soils ploughing and cross ploughing produces a deep mellowed condition which can be converted into a seed-bed with the minimum use of tined implements. The initial ploughing is done at a moderate depth before Christmas ; the cross ploughing takes place at a shallower depth when conditions are dry enough in January or February. Weathering of the two soil exposures produces the deep, mellowed condition.

The second technique applies to the heavier classes of potato soils. The land is deep ploughed (i.e. 10–16 in.) as early in autumn as possible using a full digger plough body. If this is done whilst the soil is relatively dry a thorough shattering of the furrow slice is obtained. The shattered furrow allows a deep penetration of the mellowing action of alternate wetting and drying, and freezing and thawing. No further operations are carried out until spring, when tined implements break up the deeply mellowed furrow and produce a tilth. It is advisable to use relatively straight-tined cultivators for this purpose ; curved-tine cultivators bring to the surface unmellowed clods from the deeper layers of the soil.

A third technique of growing popularity is the use in the spring of a rotovator on land deep ploughed in the autumn. On heavy land and in seasons with mild winters, this tool can be of inestimable value in preparing a tilth from the poorly mellowed land.

Each of these techniques leads to tilth production with economy of cultivation in the spring ; economy of cultivations also minimises the loss of moisture from the surface layers of the soil profile.

Once the seed-bed is prepared ridging, fertilising, planting and splitting the ridge should be completed with the minimum of delay. A drying out of the ridge surface before planting is considered to be very detrimental for early growth by most experienced growers. Any perennial weeds in the field should be dealt with in the autumn ; for couch grass deep ploughing itself is an effective weed control operation.

Choice of Seed. The selection of seed is a matter of great importance. Such factors as size of seed, the health and source of the stock and the treatment of the setts prior to planting are of paramount importance. Without good seed it is quite impossible to grow a good crop of potatoes.

For many years now it has been customary for potato growers in the more southern parts of the country to obtain their " seed " from northern districts—and it was assumed the farther north the better. Sometimes after one, more often after two, and almost always after three years' growth in the south the produce of the imported stock exhibits progressive degeneration until finally, in extreme cases, the plants are not worth growing at all. As a result of a great deal of research it has now been established that the cause of the trouble is virus (see pp. 393, 394). Virus diseases occur in a large number of cultivated plants, such as the tomato and raspberry, and their exact nature is still undefined. They are known by their effects rather than by their physical properties. A very important feature, however, is that they can be communicated from plant to plant by insects. In the case of the potato, if the virus passes from the leaf down the stem into the tuber, the plant eventually arising from such a tuber will contain the virus and its tubers in turn will also contain it—most probably in an intensified form. The effect of the virus diseases is a general decrease in the vitality of the plant, exhibited in the form of lessened vegetative development and therefore of tuber production. The degeneration may be extraordinarily rapid, and once started cannot be arrested by improved cultivation or manurial treatment.

Amongst the insects capable of transmitting viruses from plant to plant is the green fly or aphis, which is very common in the more southerly parts of England but less widely distributed in some northern districts. Thus it is that seed from the north is usually healthier and produces better crops, at least until it becomes badly infected with virus. But the mere fact that the seed originates in the north is no guarantee of its freedom from disease, for this depends first on the initial health of the stock, and then on the extent to which it has been subject to infection. These conditions rather than geographical boundaries demark good seed from bad seed, and provided the initial stock from which a bulk of seed is produced is virus-free, excellent stock can be raised in Northern Ireland and on land lying above the 450 foot contour in England and Wales.

Certified Seed. To ensure that farmers may have a guarantee as to the purity and freedom from disease of the seed potatoes they purchase, the Agricultural Departments of the United Kingdom and Eire have instituted a common system of certification. After inspection of the growing crops certificates are issued, and when seed from a certified crop is sold or offered for sale for planting in England and Wales, the seller must quote to the buyer the letters and number of the relative certificate.

Certificates are of three main kinds : " S S " (Stock seed) is seed of the highest grade intended mainly for seed production, " A " (first-quality commercial seed) and " H " (healthy commercial seed). After the certificate letter, the country of origin is indicated thus : Scotland " (Scot) ", England " (E) ", Wales " (W) ", Northern Ireland " (Nor. Ir.) ", Eire " (Eire) ", or Isle of Man " (I.O.M) ". Finally " N.I." is added in the case of those varieties which are not approved as immune from wart disease.

Thus a certificate designated " A (Scot) " would signify seed potatoes of first quality commercial standard grown in Scotland and of a variety immune from wart disease ; " H (E) N.I." signifies healthy commercial seed potatoes grown in England but a variety not approved as immune from wart disease.

The field inspection standards adopted by the several departments for the issue of these certificates are now in very close agreement. The " A " standard is reached when 99·95 per cent of the plants are true to variety and not more than 1 per cent of virus is present ; the " H " standard demands 99.5 per cent purity and permits not more than 3 per cent of virus.

In many parts of the country it pays the grower to use fresh seed each year but, where the incidence of virus is not so great, new seed every second year may suffice. In all other cases it is generally advisable to purchase each year one-third of the seed potato requirements as new certified stock.

Sprouted Seed. Sprouting or chitting the seed before planting has been shown to have considerable advantages. With early varieties the growing period may be shortened by as much as two weeks ; with main crops an increased yield of up to two tons per acre may be obtained. The sprouting is carried out under well-lighted conditions in special glasshouses or in buildings fitted with hanging fluorescent lights. Sufficient light is required to prevent spindly sprouts being formed. A temperature between 36 and 42° F. is to be aimed at ; below this temperature damage by chilling may occur ; temperatures above 42° F. lead to excessive growth in length of the chits. Chits of excessive length are liable to be broken off at planting time. The seed tubers are placed in trays, 28 to 38 lb. per tray, and these are stacked one above the other, the handles providing a spacing arrangement to allow light access. The benefits from chitting are of two forms : diseased tubers can be more readily identified and discarded than when seed is planted directly from the clamp ; but more important is the speedier emergence and early growth of the crop.

Time of Planting. The usual time of planting is from March to the beginning of May, according to the season, a start being made with the early varieties and finishing with main crops. The rule is to plant as early as soil conditions permit and when, according to locality, there is a reasonable chance of avoiding severe spring frosts. Earlies in very sheltered and favourable localities may be planted as soon as January. Whilst the use of chitted seed will to some extent counteract the loss of yield resulting from late planting, the full advantage of chitting will only be obtained when planting is carried out at the normal time.

Rate of Planting. Customary planting rates are from 15–25 cwt. per acre. Recent work has shown that although the total yield of tubers increases with rates of planting up to two tons or more per acre, the yield of ware has an optimum seed rate well below this figure. The economic optimum seed rate for ware yield is lower still and depends upon the relative value of crop and seed. Where the seed value is 1·5 that of the crop, weight for weight, the average economic seed optimum is at 1·25 tons per acre ; where the seed is twice the value of the crop the economic optimum is 0·75 tons per acre ; where the grower uses his own seed, and thus seed and crop values are the same, the economic optimum is nearer to 1·5 tons per acre.

The actual seed rate may be varied either by altering the seed size or by altering the spacing. For yields of ware grades above 1¾ in., recent work has shown that, so long as the economic optimum seed rate is used, there is little to choose between planting small seed at close spacing or large seed at wide spacing.

The usual seed size is a 2–3 oz. tuber obtained by top and bottom riddle sizes of 1¾ in. and 1½ in. respectively. The specialist seed grower often uses riddle sizes of 2¼ in. and 1¼ in. to increase the proportion of seed extracted from his crop. This results in a wider range of seed tuber weights than those mentioned. With the conventional spacing of 14 in. on 28 in. rows an average seed size of 2½ oz. requires 16,000 tubers, or 21 cwt., per acre.

In the potato crop the true plant population is the number of sprouts which develop to form independent plants ; it is therefore the product of the number of tubers planted and the average number of shoots developed from each tuber (i.e. the number of hills × the shoots per hill). Some varieties (for example King Edward) produce more sprouts than others (for example Majestic). The effect of this is to increase the number of tubers in the crop, to decrease their average size and therefore to decrease the ware percentage. These high shoot-producing varieties need to be planted at less than the average seed rate to obtain high yields of ware. Very early chitting, starting as soon as the crop is lifted, improves matters. The seed should be placed in a warm chitting house until the sprouting commences and then maintained at a low temperature (i.e. below 42° F.) until planting time. In this way seed with only one to two chits per tuber may be obtained. Single-chitted tubers are also of considerable advantage in producing first early crops.

The seed producer's main objective is a high yield of seed-sized tubers. This can be obtained either by planting normal seed at close spacing or ware-sized seed at normal spacing. As ware-size tubers are the by-product in the seed-producing industry, the second procedure is more appropriate.

The planting can either be done by hand, in which case casual labour is frequently used, or by machine. Under suitable conditions machine planting can be operated with a considerable saving of man hours ; figures quoted are hand planting, average 18 man hours per acre : machine planting, 6 to 11 man hours per acre according to type of machine.

Post-planting Cultivations. These are designed to control seedling weeds. About 10 days after planting the ridges are harrowed down, so destroying a crop of seedling weeds. This operation may be followed by a further earthing up and harrowing down at suitable intervals to destroy two further crops of seedlings. After the potatoes have emerged further weed control is done by inter-row cultivations. The final operation is to earth up the crop once again before the tops meet in the row. Certain herbicides incorporated into the surface layer of the soil show promise of eliminating these weed-control operations. These methods of weed control are satisfactory for annual but not for perennial weeds ; the latter should be dealt with in the autumn.

With seed crops " roguing " is necessary. This involves the digging and removal of any plants affected by virus disease or any plants that are not true to type. This is carried out in May and again before the end of June.

In districts subject to potato blight, spraying is a sound insurance. The first spraying should be done when the haulms are well grown, in dry weather and before the disease appears, for in dealing with blight the measures are preventive and not curative. A second spraying is usually given about three weeks later but the correct dates for spraying vary from district to district and season to season. Full details of the procedure are given on pages 365 and 366.

A late attack of blight may call for spraying with 10–12 per cent sulphuric acid to kill the haulms which carry the disease spores. In seasons when the haulms remain green they are troublesome to the lifting implements and it is now becoming quite common to spray such crops with sulphuric acid to kill them off. Tar oil fractions (T.O.F.54), and sodium chlorate at 1½–2 per cent strength, can also be used.

Irrigation. In the dryer parts of the country and particularly on the sandy soils in these areas, irrigation is considered to be a profitable operation provided the water can be applied at a cost of about 50s.–60s. per acre-inch (i.e. per 22,000 gal). The operation is carried out before the excess of evaporation over precipitation results in a soil-water deficit harmful to the crop. Precision in the operation involves the preparation of water-balance sheets. This may be done by the method described in the Ministry of Agriculture's Technical Bulletin No. 4 entitled " The Calculation of Irrigation Need ". Certain data for the calculations are given in the Bulletin, but current season's rainfall and sunshine data are required from the nearest meteorological station. Simple instruments which can be used on the farm to give direct readings of irrigation need are being devised and will soon be available commercially (see also p. 210).

Harvesting. Lifting of early varieties commences towards the end of May. Much of this task is hand work and the tubers are packed in barrels and despatched to the market immediately. The maincrops, however, are mostly lifted by machinery, which may be of the spinner type, the elevator digger or the complete harvester which lifts the crop and elevates it into carts or bags. The maincrops are stored in long clamps or pits to be sorted and marketed at favourable opportunities during the winter. The clamps are first given a good covering of straw and finally about 8 in. of soil to render them both frost- and waterproof. Many potatoes are now stored between walls made of baled straw. The practice of storing under cover in sheds or barns is gaining ground since a good deal of labour is thereby saved and the sorting can be carried out under more congenial working conditions. The sorting is into " ware " or sale potatoes ; " seed " which may or may not be used a further time ; and " chats " which are so small as to be fit only for stock food.

After the potatoes have been lifted the ground is harrowed to expose any tubers still left in the ground, and these are then collected and should be stored separately since it is probable that they will be bruised and may not store well.

The production of a potato crop by present techniques involves the use of approximately 140 man hours and 30 tractor hours per acre. Of this, 70 to 80 man hours are required for harvesting and a further 25 for clamping. Under suitable conditions fully mechanised lifting can, at a conservative estimate, save 20 man hours per acre with an increase of tractor hours from 13 to 19. Elevator diggers are rather more efficient than spinners ; where two-row models, which deposit two rows into one, are used improved efficiency is obtained ; where two-row lifters are used on the " batch lifting " system instead of the " round and round " system still further improvement occurs. The spinner type of harvester is capable of working under wetter conditions than elevator diggers or complete harvesters. Similarly, a high population of clods or stones will interfere with the work of a spinner to a less extent than the other types. With all harvesting methods care is needed to avoid bruising or cracking the tubers.

Yield. The average yield of ware per acre is 6–8 tons, but on good potato land in favourable years crops of 15–20 tons per acre are not uncommon. The average yields of potatoes have increased to some extent in recent years. The increase has been nothing like so great as that with the cereals ; wheat yield for instance has increased by approximately 27 per cent since the period 1934–43 ; whilst potato yields over the same period have only increased by 10 per cent.

This smaller increase can probably be attributed to the slower progress in the production of better varieties compared with the cereals.

MANGELS AND FODDER BEET

Mangels belong to the genus *Beta* of the Family Chenopodiaceæ, which also includes sugar beet, fodder beet and red beet. It was some time after turnips became a recognised farm crop in this country that mangels were introduced and their cultivation is more or less restricted to the east and south-east, where the higher general mean temperature is more suited to the successful growth of the crop. In the north of England and Scotland swedes and turnips are much more widely grown than mangels.

Mangels produce a much higher yield of dry matter per acre than swedes and turnips. The dry matter content of the mangel varies with different classes and is of the order of 7–15 per cent. Whilst this is not appreciably higher than that frequently obtained in swedes the weight of mangels produced per acre is much greater and, under good soil and climatic conditions and with generous treatment, yields of 50 tons per acre are not uncommon. Fodder beet, although giving lower yields of roots than mangels, have a higher percentage of dry matter and will produce as much, or even more, dry matter per acre than mangels.

Varieties. The number of varieties of mangels in general use is very considerable, and wide variations in cropping capacity, dry matter content, root shape and skin colour occur. The varieties of fodder beet are more restricted and are mainly of continental origin. As these crops are normally cross pollinated they have to be grown in isolation for seed production and, unless strict selection within the stock is maintained, a named variety may change in character over the years. Mangels, fodder beet and sugar beet are best regarded as a continuous series. Mangels have a larger size of individual roots but a lower dry matter percentage than sugar beet, whilst fodder beet is intermediate for both attributes. Similarly, mangels have a smaller proportion of the root in the soil than fodder beet, whilst sugar beet has only a relatively small crown of the root above soil level. This character determines the ease or otherwise of lifting.

Varieties of mangels and fodder beet can be grouped under four main headings :

1. Low dry-matter mangels (D.M. range 9 to 12 per cent)
2. Medium dry-matter mangels (D.M. range 13 to 15 per cent)
3. Medium dry-matter fodder beet (D.M. range 14 to 18 per cent)
4. High dry-matter fodder beet (D.M. range 19 to 20 per cent)

The low dry-matter mangels are further divided into globe and intermediate types, the latter containing the tankard-shaped varieties. The chief difference between these two groups is that the former have rather more of the root above the ground surface. The skin colour of all groups can be white, yellow, orange or red although the two varieties listed in group 4 are both white skinned. There is little to choose between the dry matter yield per acre in the two mangel groups ; the two fodder beet groups produce on the average approximately 10 per cent more dry matter per acre than the mangels. Further information about varieties is given in Appendix V.

The amount of dry matter per acre and the dry matter percentage are greatly dependent upon conditions of growth. Dry matter percentage is reduced in a wet season although the total dry matter yield per acre may be increased. Similarly a high plant population will give rise to roots of a relatively high dry-matter content within limits set by the variety. Extensive trials in several countries have shown that the feeding value of these crops can for all practical purposes be estimated from the quantity of dry-matter present.

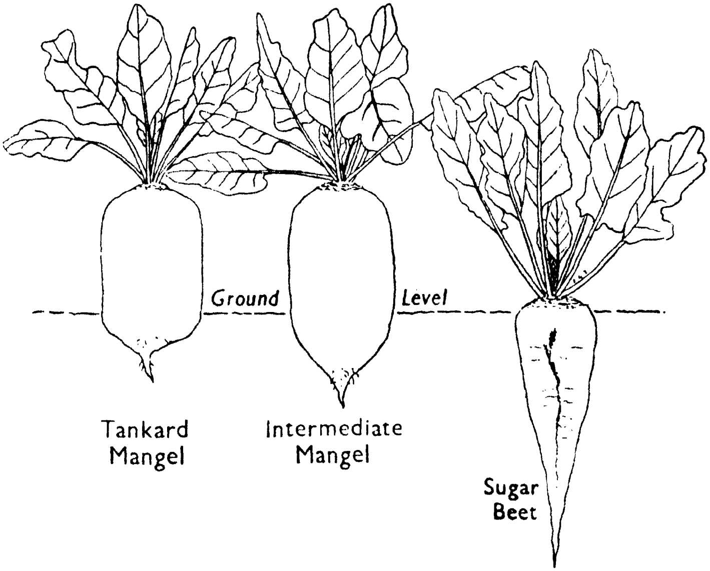


Fig. 37.—Mangels and Sugar Beet.

Position in Rotation. Mangels occupy a part of the root shift of the rotation and thus usually follow, and are succeeded by, a cereal. It is not uncommon, however, on many farms to grow the crop on the same piece of land for a number of years in succession. Usually an area near to the homestead is selected to ease the burden of carting the crop home and the farmyard manure out to the land. Generous manurial treatment year after year builds up the fertility and large yields result ; the repeated cleaning of the land eradicates weeds and enables the cost of hoeing to be reduced year by year. It is because mangels are relatively free from pests and disease that this practice is possible.

Manuring. In common with sugar beet both mangels and fodder beet are very sensitive to soil acidity. Suitable applications of lime should be given to correct the condition where it occurs. This should be done early enough for the lime to act before the crop is sown. In practice it is preferable for it to be applied either to the preceding crop or, at the latest, in the autumn before mangels are sown. The three crops also respond to N.P.K. fertilisers and, in addition, to sodium. The latter is usually given in the form of agricultural salt at the rate of 3 cwt. per acre. Many fertiliser experiments have been carried out on mangels and sugar beet but a smaller number on fodder beet. Data exist for the economic optima of N, P_2O_5 and K_2O, but a difficulty arises in attaching a value to mangels and fodder beet for the purpose of the calculation. Where an arbitrary value of £2 to £2½ per ton is given to mangels and an equivalent value, in proportion to their dry matter content, to fodder beet, the average economic optima may be taken as being N—100 ; P_2O_5—50 ; K_2O—150 units per acre.

Where agricultural salt is applied the potash may be reduced to 100 units ; where F.Y.M. is used the optimal may be reduced by 30, 40 and 75 units of N, P_2O_5 and K_2O respectively per 10 ton dressing of F.Y.M. Other adjustments should be made where the soil by analysis shows deficiencies or excesses of individual nutrients. Where the nitrogen is supplied in the form of nitrate of soda (up to 3 cwt. per acre) there is no need to apply agricultural salt.

Fertilisers for these crops are usually broadcast on the seed-bed before drilling. Agricultural salt needs to be applied about four weeks before drilling or, where this is impracticable, it may be applied the previous autumn. Combine drilling of fertiliser and seed is dangerous ; side band placement is safe and gives a response in the early stages of growth but has no advantage over broadcasting in the final yield. Some farmers top-dress mangels with nitrogenous fertilisers soon after singling. On very light soils in wet seasons this practice probably has a distinct advantage over that of placing all the nitrogen in the seed-bed.

Cultivation and Sowing. A fine, firm and moist seed-bed is required to obtain a satisfactory establishment of the mangel or fodder beet crop. With medium and heavy land this means autumn ploughing so that mellowing of the furrow may be obtained. This in turn leads to an economy of seed-bed cultivations in the spring. It is customary these days to sow the crop on the flat and so a deep tilth such as that described for potatoes is not necessary ; where the crops are still sown on the ridge similar techniques for obtaining the depth of tilth as described for potatoes apply. It is necessary to obtain control of perennial weeds the previous autumn either by stubble cultivations, deep ploughing or by the newer herbicidal methods. In preparing the seed-bed an even and level tilth is required to facilitate precision inter-row cultivations. " Round and round " ploughing or one-way ploughing, helps in the achievement of this objective by the elimination of ridges and furrows. The use of the " scrubber " or " float " in the final stages of seed-bed preparation is also an advantage.

The crop is usually sown at the rate of 10 lb. of seed per acre from early April to the end of May, the earlier the better. The depth of sowing is ½–1 in. below the surface. The final plant population is obtained by singling. For high yields of dry matter per acre and for high percentage dry matter a plant population of 25,000 to 30,000 plants should be the aim. This can be achieved by drilling on a 22 in. row and singling to 10½ in. Where the crop was sown on the ridge row spacings 24–26 in. were common ; the low plant population so obtained, whilst giving large individual roots, gave a lower percentage dry matter and lower dry matter yields. Economy in achieving the plant population by mechanisation is described in more detail in the case of the sugar beet crop. Singling should be done at the 4-true leaf stage ; in practice it usually extends from the 2-leaf to the 6-leaf stage.

The steerage hoe should be used in the crop as soon as the seedlings are visable and should be continued as necessary until the plants are large enough to smother further seedling weed growth. The herbicide PCP may be used as a pre-emergence spray ; TCA or CIPC at the recommended rate, as a pre-sowing spray, is also useful for the control of certain weeds, including the gramineous weeds.

Harvesting. The mangel crop is harvested some time in October or early November before severe frost sets in. The roots should be injured as little as possible in lifting to prevent bleeding ; the tops are either cut or twisted off and the roots are left untrimmed. The practice of clamping mangels with the tops left on has increased in recent years and does not appear to affect adversely the keeping quality of the roots and, being more economical of labour, has much to commend it. After remaining a day or two on the surface to dry, the roots are carted to the pit or clamp, where they are carefully stacked together, and then covered first with a generous layer of straw well laid in position and then with a layer of soil to protect them from frost during the winter. A ventilating shaft, consisting of a bunch of straw or a drain-pipe, should be inserted at a distance of every 6 or 8 yd. Mangels are not fed to stock until the New Year to permit full maturation to take place. Failure to observe this is likely to cause severe scouring of the stock. They should not be fed to male sheep since this brings about urinary trouble. Several of the mechanical root harvesters now on the market can be adapted to deal with the mangel and fodder beet crop.

Yield. The average yield of mangels is around 20 tons per acre. Under favourable conditions of soil and climate, and especially following generous manurial treatment, yields of 30–50 tons per acre can be obtained.

SUGAR BEET

The wild beet is found in its normal habitat along some of the more southerly European coasts. There it develops a fine slender root and may be an annual, biennial or perennial. Contrary to general belief, individual roots of this species may contain more than 14 per cent of sugar.

As an agricultural crop sugar beet has been known on the Continent, particularly in France and Germany, for over a hundred and fifty years, but its cultivation in Britain on an extensive scale did not begin until 1920. In that year some 3,000 acres were under the crop ; today the acreage, over 400,000 acres, is an indication of the tremendous rise to popularity of the crop, which has now a secure place in British farming systems.

The cash value of the sugar-beet crop depends very much upon the total quantity of sugar produced per acre, i.e. weight of crop multiplied by the percentage of sugar in the root. The percentage of sugar in the root is subject to considerable fluctuation, due to season, variations in the character of the soil, to a minor degree to the feeding of the plant, and finally to the variety itself. In general it is reasonably safe to assume that sugar content is largely outside the farmer's control ; the farmer should therefore concentrate on the attainment of a high yield per acre in order to make the crop remunerative. The grower has, however, valuable by-products in the shape of spent pulp from the factory and the crown and leaves of plants left in the field, both of which are excellent for cattle or sheep and replace roots in the dietary of these animals. Since its introduction many farmers have ceased to grow feeding roots and have replaced them by sugar beet ; this not only provides a direct cash return but also enables about the same head of stock to be maintained, the by-products of the beet replacing swedes and turnips.

The plant is a white-skinned, white-fleshed biennial producing a more or less conical-shaped root weighing on the average about 2 lb. and possessing a root capable of penetrating the soil to a depth of 12–15 in. (Fig. 37). The plant may send up its flowering stem in the first year, when it is said to " bolt " : this tendency is hereditary and some strains are more liable to it than others. In all strains, however, too early sowing or a severe check during early growth are conditions which predispose to " bolting ".

Provided there is an adequate supply of lime present and that they are deep and relatively free from stones or a plough pan, there are few soils which will not grow sugar beet. The suitability of any particular soil, however, is determined largely by various economic aspects ; light soils on the whole are to be preferred because the roots are easier to lift and are relatively free from soil when lifted. Under such conditions yield is dependent upon an adequate rainfall. Heavy soils, on the other hand, have the drawback of needing additional cultivation to bring them to a suitable degree of tilth for the crop, and unless early autumn ploughing is carried out and a good frost mould obtained, cloddy seed-beds are likely to result. Without a fine friable tilth it is very difficult to obtain an even plant, the first essential for good yields. On heavy land considerable difficulty is experienced in lifting the roots and carting them off, whilst the amount of soil adhering to the roots, and for which a deduction (dirt tare) is made at the factory, is likely to be unduly high. Fen soils produce good yields of beet but the sugar contents are low : in general, therefore, the ideal soils for growing this crop are the medium loams.

Varieties. The efforts of plant breeders have been directed towards securing the greatest yield of sugar per acre, and to a very large extent this has been accomplished by gradually raising the percentage of sugar in the roots. It is by no means uncommon for this to register 20 per cent or over, although the average is in the region of 15–16 per cent. Gross yield, too, has been greatly improved, whilst by selection better conformation of the root, which facilitates easier lifting, has been obtained. Branching and fanged roots have largely been eliminated, and in the best varieties the root is now cone-shaped. Further but smaller modifications are the small-leaved tops of varieties produced for growing on rich soils, and non-bolting strains for the earliest sowings.

The seed of the varieties in the British Isles is at present derived mainly from original foreign stocks, but is all grown in this country. For purposes of comparison the varieties are divided into three types—" E ", " Z " and " N ". The " E " types are those producing large crops with not particularly high sugar content ; the " Z " types are those of decidedly high sugar content, and the " N " types represent what may be regarded as a combination of the characteristics of " E " and " Z " types.

For some years it has been suspected that breeding programmes based upon intensive selection for the attributes of high sugar percentage, high potential root yield, satisfactory root shape and top characteristics, together with low bolting propensities, have just about reached the limit of their potential. In consequence further substantial improvement must involve a new breeding technique. In recent years the breeding of polyploid varieties has been undertaken. This involves increasing the normal two sets of chromosomes in each cell to four sets or more, a process that can be achieved by treatment of the fertilised ovule with colchicine, or other chemical compounds, at a suitable stage. Polyploids usually show greater vigour and reach a greater size than diploids in most plants. So far two such polyploid varieties have been tested and marketed. One is about average for yield of sugar per acre and the other is 2-4 per cent above average. It seems likely these modest improvements will be exceeded in the future. Further developments have been directed to the production of mono-germ (i.e. single seeded fruit) varieties. Such types of beet already exist but the mono-germ character appears to have been linked with low yielding characteristics. Hybridisation to combine in one variety the two characters would have considerable advantages from the point of view of simplifying the singling operation.

For many years the National Institute of Agricultural Botany has tested the behaviour and comparative yield of different strains in accurate field trials situated in the principal beet-growing areas. The present list of recommended varieties is given in Appendix V and further details may be obtained from Farmers' Leaflet No. 5 of the N.I.A.B.

Position in the Rotation. On most farms sugar beet occupies part of the root break, and as already indicated may in some cases replace roots completely. Sugar beet is always grown on contract for the factory which is ultimately to handle it. As the grower is responsible for delivering the roots to the factory, which he does by rail, road, or water, wherever possible fields are selected in close proximity to a hard road. The carting of such a bulky crop long distances over soft tracks in wet weather is very expensive at best, and sometimes impossible. In order to prevent the danger of sugar beet eelworm (which causes the condition known as " beet sickness ", menacing the growth of the crop in this country as has happened on the Continent) the sugar-beet factories do not allow growers to follow beet with another beet crop or a Brassica crop at a closer interval than two years (see p. 434).

Manuring. Sugar beet is very sensitive to soil acidity, and where it occurs it should be corrected by lime applications given early enough for it to act before the crop is sown, as described for mangels. Where farmyard manure is available 10-12 tons per acre may be ploughed in in the autumn. Spring applications tend to promote fanging of the roots ; many growers apply dung to the previous crop rather than direct for the beet itself. Whether or not manure is given, the crop requires N.P.K. fertilisers and also benefits from an application of sodium. The latter is applied in the form of agricultural salt either one month before the crop is sown or, alternatively, in the autumn before sowing. Although 3 cwt. are regarded as adequate, experiments have shown that 5 cwt. of agricultural salt in the absence of potash leads to an average increase of 5 cwt. of sugar per acre ; in the presence of potash the response is approximately 2½ cwt. sugar per acre.

The experimental data for the calculation of optimal rates of nitrogen, phosphoric acid and potash are more extensive than those for any other British crop. With fertiliser and crop prices of recent years the average optima are : N, 100 units ; P_2O_5, 50 units ; K_2O, 150 units per acre. Where 3 cwt. of salt are used the potash may be reduced to 100 units.

These average optima need modification where the soil is below or above average in P_2O_5 and K_2O. On fen peats the nitrogen needs to be reduced by 50 units, and the P_2O_5 and K_2O increased by 20 units. Rates of nitrogen application above the optima, whilst not giving an economic increase of root or sugar yield, will lead to an increase in yield of tops. Where 10 tons per acre of F.Y.M. are applied, the N, P_2O_5 and K_2O may be reduced by 30, 40 and 75 units respectively.

Sugar beet on certain soils may suffer from deficiencies of the two micro nutrients boron and manganese. The former causes a condition known as brown-heart and is liable to occur on sandlands in dry years particularly if the land has been over-limed. It may be rectified by careful applications of 20 lb. of borax per acre. Manganese deficiency is common on neutral or alkaline soils with a high organic matter content. It often occurs on fen peats. The deficiency causes a condition known as " speckled-yellows " and it is most effectively controlled by spraying 10 lb. per acre of manganese sulphate on to the leaves as soon as the deficiency makes its appearance in the crop (see p. 191).

As with mangels, sugar beet will show a response in the early stages of growth to side-band placement of the fertilisers. The final yield is, however, no better than where the fertiliser is broadcast. Direct contact placement of fertiliser and seed can cause severe injury to germination. Sugar beet on very light sands in a wet spring may benefit from a top dressing of nitrate of soda at the rate of 1 to 2 cwt. per acre.

Cultivation and Sowing. The seed-bed for sugar beet should be very similar to that described for mangels. The field should have been cleaned in the autumn, the dung applied, and the ground well and deeply ploughed before the severe winter weather sets in. Subsoiling is advantageous, especially on soils which have a hard pan at or about normal ploughing depth. The elimination of ridge and furrow by the use of one-way ploughs is an aid in the production of the level seed-bed required for precision inter-row cultivations. In spring the fine and firm seed-bed needs to be prepared from the frost-mellowed plough furrow with the minimum number of operations, both from the point of view of general economy and in order to conserve moisture. The first operation is designed to disrupt the plough furrow and is usually done by a tined implement working to a depth of 4–5 in. Subsequent operations are usually carried out by harrows and Cambridge rollers. On the heavier soils a " float " or " scrubber-harrow " is often a considerable help in achieving the desired standard of seed-bed. Badly prepared seed-beds result in poor and irregular seedling establishment which, in turn, hinders singling and inter-row cultivations.

Normally, the sooner sugar beet is drilled after the middle or end of March the better the chances of obtaining high yields and high sugar content. The actual date of sowing is, however, very dependent upon the condition of the soil for seed-bed preparation. It is often a practice to stagger the sowing at two or three dates separated by ten-day intervals, in order to spread singling operations. For the earlier sowings of the crop, low bolting varieties should be chosen.

The natural " seed " is really a cluster of fruits each of which may contain one viable true seed. As the true seed is quite small it needs to be sown in a moist tilth not deeper than ¾ in. Where the natural " seed " is used about 15 lb. per acre are normally sown. More than one seedling can develop from the fruit cluster and this makes the singling operation relatively slow. Rubbed and graded seed is produced by passing natural " seed " between a rubber pad and a revolving emery wheel and grading the reduced fruit clusters so obtained. This has the effect of increasing the proportion of mono-germ clusters. Rubbed seed is sown at the rate of 8–10 lb. per acre.

The operation of drilling can be carried out in a number of ways using multi-purpose drills, drill units on the tractor tool-bar or precision drill units. The precision drills deliver seed down a very short coulter tube at regularly spaced intervals of 1–2 in. Rubbed and graded seed is essential with this kind of drill and the quantity of seed used per acre is very much less than with ordinary drills.

Covering the seed may be done by harrows, by flat roller wheels behind each seeder unit or by hollow cage-type rollers. The latter are a considerable advantage on soils which have a tendency to form surface " caps " or " crusts " and so impede seedling establishment.

Post-drilling Operations. These take three distinct forms: the production of the required plant population ; weed control ; and the protection of the crop from disease or pest damage.

The plant population is achieved by the combination of the coulter spacings at drilling and by the singling distance within the row. A large number of experiments in this country has shown that beet yields increase up to and beyond 30,000 plants per acre. The yield response to plant population levels off when the latter increases much above 30,000 plants per acre and, as the cost of handling the larger number of plants also increases considerably, it is considered that the economic optimum lies somewhere between 25 and 30 thousand plants per acre. Plant populations of this size may be obtained by row widths of 18 in. with 12½ in. singling distance, up to 22 in. with 10½ in. between plants. An increase in plant population achieved by making the rows narrower has a greater yield benefit than the same population achieved by closer spacings between plants within the row. Narrower rows increase the total length of row per acre and, as both the labour of singling, seconding and lifting is largely determined by the length of row per acre that has to be dealt with, costs rise accordingly. In practice, row widths are determined by their relation to the width and the positioning of the tractor wheels. Row widths of 20–22 in. are most commonly used and these require singling to 11½ in. and 10½ in. respectively.

The operation of singling needs careful timing. The ideal time is considered to be at the 4-true-leaf stage. Delay up to the 6-true-leaf stage has little effect upon final yield particularly when rubbed seed is used. Serious loss of yield (i.e. up to 1½ tons per acre) occurs when the operation is delayed, by as little as one week, after the 6-true-leaf stage. The loss of yield is smaller where rubbed seed is used : bunching also reduces the loss.

It takes approximately 145 man hours per acre to produce and harvest a crop of sugar beet ; of this, 55–60 man hours per acre are used in singling, seconding and other forms of cleaning the crop. Much attention has been directed to reducing the labour used in these operations. This has been attained by using rubbed seed, by precision drills and by machine thinning or by cross blocking. The smaller proportion of " doubles " obtained where rubbed seed is used itself reduces the singling time by approximately 10 per cent. The wider spacing between individual seedlings obtained by using the precision drill still further speeds the operation. On exceptionally level seed-beds and with even brairds the use of the tractor hoe at right angles to the drill row produces a series of evenly spaced bunches which are subsequently singled. This is the process of cross blocking which can, under suitable conditions, lead to appreciable saving in labour. Recent developments in down-the-row thinners have, however, achieved even greater success in reducing labour without prejudice to the final plant population. The thinner consists of a number of hoe blades attached to a rotating head. As the machine travels along the row the rotating hoe blades strike and leave alternate lengths of row. The number and size of hoe blades used are adjustable. The number and size selected depends upon the beet stand and this is determined by counting, using a special frame, the number of inches in 100 occupied by seedling beets. This is expressed as the percentage of beet-containing inches. After thinning, 10 beet plants per 100 in. of row will normally be required. Where there are, say, 36 per cent of beet-containing inches, a first thinning using eight blades of a size to cut and leave alternate 1¾ in. will reduce the number to approximately 18 per cent. A second thinning a few days later choosing double the number of appropriate smaller sized blades will reduce the beet-containing inches to the desired 10 per cent. In each case the size and number of blades are selected by reference to calibration charts using the figure of percentage beet-containing inches obtained by counts, and the final figure required. This system of mechanical thinning is known as the Windsor system. A final trimming of the thinned stand of seedling beets by hand hoes is required. The success of the method is determined by a level seed-bed, an even braird of seedlings and correct adjustment of the thinners. Labour saving of approximately 25 per cent is claimed with twice-over thinning plus hand trimming, compared with hand operations only.

Weed control in the sugar beet crop is usually carried out by steerage hoes and the first operation should start as soon as the beet seedlings are visible. The process should be continued until the size of the beet is such as to render it impossible without damage to the leaves. For the early hoeings L-type or disc-type side hoes are required but A-type hoe blades may be used in the later stages. Pre-sowing applications of TCA or IPC or pre-emergence applications of PCP at the recommended rates, have been shown to be successful chemical methods of early weed control in the crop.

Amongst many diseases and pests that can attack the sugar beet crop Mangel Fly and Black aphis are two which occur with some frequency according to season. They are described in Chapter XIV.

Irrigation. In some of the dryer parts of the country irrigation is now considered to be a profitable operation on the sugar beet crop. The same remarks apply to irrigation on this crop as on the potato crop to which reference should be made (p. 262).

Harvesting. A start with lifting is usually made at the end of September, although maximum sugar content may not be reached until mid-October. Good weather greatly facilitates the work and most growers are willing to sacrifice a little weight per acre or some sugar content in order to get well ahead while conditions are favourable. The roots are first loosened with a beet plough and later are pulled by hand, knocked to free them of soil and then topped by removing the complete " crown ".

In recent years great strides have been taken in the mechanical harvesting of sugar beet. In 1946, less than 1 per cent of the acreage was harvested in this way, but by 1957 it had increased to 55 per cent. There are two systems available, complete harvesters which top, lift, clean and elevate the beet into trailers ; and two-stage harvesters in which one unit tops and a separate unit lifts and cleans the beet. The complete harvesters are suitable for the larger growers or for contractors, and on the average they handle 50 to 60 acres per year although some are capable of doing up to 150 acres in one year. Out of the 150 man hours required to produce and harvest an acre of sugar beet approximately 68 man hours are needed for the hand pulling, knocking and topping system of harvesting. Complete harvester systems can reduce this to 26 man hours per acre with an increase in tractor hours of 2 per acre. The two stage harvesters, where the beet is left in the windrow, can reduce operations to approximately 32 man hours with an increase of about 4 tractor hours per acre. The efficiency of mechanised lifting varies with the type of machine used, the skill in adjusting it for the particular crop, and the soil conditions. They all work best in crops where an even population of well developed beets occur.

After the sugar beet is harvested the tops which remain in the field make excellent food for either sheep or cattle: they should be allowed to wilt for ten days or so. For sheep the tops are usually folded on the land. They are generally carted off for cattle and fed on grass or in yards. When more tops are grown than can be comfortably fed in this way, the surplus, whilst still in sound condition, can be made into silage. The pit or clamp method is generally the simplest and most satisfactory to use. When feeding tops to cattle it is always advisable to feed some ground chalk in the ration to counteract any tendency to scour.

Yield. The crop is purchased by the sugar factory at a fixed price per ton of washed beet registering 15½ per cent sugar. For every 1 per cent above, or below, the average sugar content a fixed amount is added or deducted as the case may be. An average yield of washed roots is 11–12 tons per acre with a sugar content of slightly less than 16 per cent, but upwards of 20 tons per acre may be obtained under ideal conditions. According to season and other factors the sugar content may be as high as 20 per cent. There is approximately the same weight of tops per acre as of roots. These are equal in feeding value to swedes.

TURNIPS AND SWEDES

Turnips were introduced to this country as a farm crop early in the eighteenth century and swedes towards the end of the same century. The incorporation of roots into the farming system is generally ascribed to the enthusiasm of Lord Townshend, who demonstrated

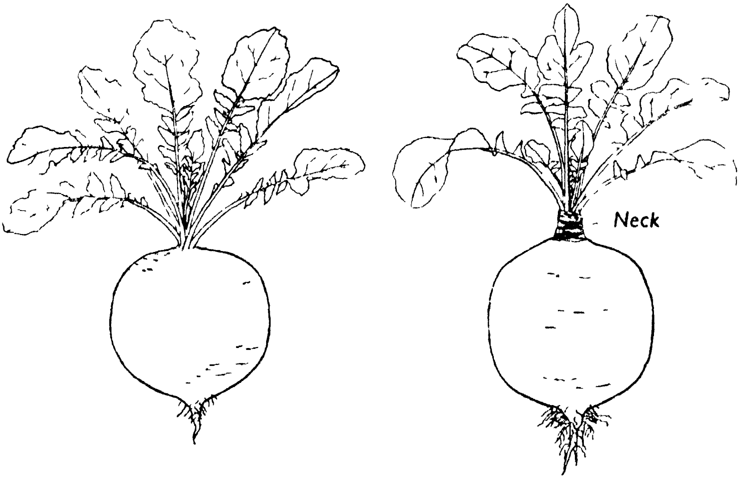


Fig. 38.—Turnip and Swede.

on his estate in Norfolk the value of roots for feeding cattle and the beneficial effect they had on the following cereal crop. By utilising Tull's turnip drill Townshend was able to grow the crop in rows and to make use of inter-row cultivation in a growing crop as a means of weed control other than by the expensive bare fallow. Eventually and as a result of his experiments, Townshend formulated a rotation of crops, subsequently known as the Norfolk Four Course, which consisted of turnips, barley, clover and ryegrass, wheat. This system formed the basis for all crop rotations on light to medium loam soils.

Swedes are distinguished from turnips by the extended stem (generally called a " neck ") from which the leaves arise, and by having smooth, ashy-green leaves in contrast to the hairy, grass-green leaves of turnips which arise direct from the bulb itself (Fig. 38). The most important economic difference between turnips and swedes, however, is the amount of dry matter they contain : in turnips it ranges from 7½ to 10 per cent, and in swedes from 10 to 13 per cent. White turnips contain the smallest quantity of dry matter and green-top swedes the largest. Finally, swedes have a longer period of growth and are much hardier than turnips, and can be stored satisfactorily for feeding during the winter in conjunction with coarse fodders for which they form an excellent supplementary feed.

Both turnips and swedes are more suited to the humid areas of the North and the West compared with the drier regions of the country. In the latter areas they tend to suffer severely from mildew and late sowing of the crops has long been used as a means of, at least, partial control of the disease.

" Pot " swedes and turnips are produced in some areas. They need to be uniform globe-shaped varieties grown at a relatively high plant population so that the individual roots do not become too large. In addition good " pot " swedes have short necks.

Varieties. Turnips are classified under three main headings, white, soft yellow and hardy yellow turnips. Swedes can be grouped into purple, bronze and green-topped varieties.

White turnips are so described because they are white-fleshed, but the outer skin may be white, green, purple or mottled green and purple. These roots grow very rapidly and when sown in late spring are ready for use in early autumn, the leaves and bulb being consumed together. If they happen to be left in the ground and encounter a mild winter they will continue to grow, and a late sown crop may then be consumed in the spring. White turnips can thus be utilised to provide keep over an extended period and are consequently used extensively on sheep farms. They contain 7½–8 per cent dry matter.

The soft yellow turnips and the hardy yellows are yellow-fleshed and contain from 8 to 10 per cent dry matter, the hardy yellows being almost equivalent in feeding value to the purple-topped varieties of swedes. They are somewhat hardier than white turnips and are generally regarded as intermediate in value between soft white turnips and swedes.

Swedes may be white-fleshed or yellow-fleshed, but the latter are the more commonly cultivated. The outer skin of the yellow-fleshed types may be purple, bronze or green. As a class they have a much higher dry-matter content than turnips, a longer growing period and a high degree of adaptability to the cooler, moister conditions of the north and west. Their cultivation under the warmer, drier conditions of the midlands and south is attended with some risk. The purple-topped varieties having 11 per cent dry matter produce the heaviest yields, but are the poorest swedes for keeping ; the green-topped varieties with 13 per cent dry matter are the best keepers, but give a much lower yield ; the bronze-topped varieties can be regarded as intermediate between these extremes. Within each group of both turnips and swedes there is a number of named varieties.

Between 1953 and 1959 the N.I.A.B. have had in trial some 130 named varieties of purple- and green-skinned swedes. In this series of trials the highest dry matter percentage was lower than those quoted above and it occurred within the purple-skinned group ; but the average dry matter percentage of the green-skinned group was greater than that of the former. The figures were : Purple-skinned group, mean dry matter 9·3 per cent (range 8·3–10·4 per cent) ; Green-skinned group, mean dry matter 9·9 per cent (range 9·7–10 per cent). The generally lower dry matter percentages may be a reflection of altered methods of growing the crop : higher levels of available soil nitrogen, decreased plant populations and later dates of sowing, all tend to decrease the dry matter percentage. The N.I.A.B. data also indicated that each of the green-skinned and two of the purple-skinned varieties listed showed resistance to the club root disease. Also, two of the purple-skinned types showed some resistance to mildew. For further details see Farmers' Leaflet No. 7 of the N.I.A.B.

Position in Rotation. Turnips and swedes are the principal cleaning crop in the rotation in those districts where they are grown extensively ; hence they always follow a cereal crop and in turn are followed in most cases by a cereal crop. Occasionally when the land is very filthy two root crops may be taken in succession in an endeavour to clean the land thoroughly before sowing to corn again.

Manuring. Turnips and swedes show unsatisfactory growth under conditions of soil acidity. Not only is a low pH directly detrimental to the crop, but also such a condition increases the chances of severe attacks of the club root disease. Soil acidity needs to be corrected by suitable dressings of lime applied early enough to act before the crop is sown. Excessive applications of lime on light soils may lead to boron deficiency which produces a condition known as " brown-heart " or " raan ".

Traditionally, turnips and swedes are given large dressings of phosphate but only moderate dressings of nitrogen and potash. As a result of pre-war experiments, 80 units of N, 140 units of P_2O_5 and 130 units of K_2O are calculated to be the average optimal applications assuming present prices and a crop value of £2 per ton. Revised estimates suggest that 80 units of N, 80 units of P_2O_5 and 80 units of K_2O are more appropriate. Where swedes are to be left in the ground for winter folding 80 units of N is too high and 40 units would be safer. High nitrogen reduces the dry matter percentage and decreases the frost hardiness of the crop.

Where 10 tons per acre of farmyard manure are applied to the crop, the fertiliser applications may be reduced to approximately half of the revised average optimal. Where deficiencies in soil phosphate or potash are known to exist, supplementary dressings are required.

In areas where turnips and swedes are sown on ridges the fertilisers can be applied on the flat before ridging. The act of ridging then concentrates the fertiliser in the ridge. Where the crops are sown on the flat it has been shown that side-band placement of the fertiliser 2 in. to the side and 1 in. below the seed gives a better yield than broadcast applications. Direct contact placement of fertiliser and seed can cause severe injury to germination and establishment.

Cultivation and Sowing. Turnips and swedes, being small seeded, require a fine and firm seed-bed which needs to be prepared with minimum loss of moisture. In Scotland the crop is often sown on ridges, but in most other areas it is sown on the flat. Where ridge sowing is adopted a deep fine tilth is required to permit the ridges to be formed ; where sown on the flat a shallow tilth only is required. Cultivation operations are arranged to produce either of the two types of tilth mentioned. The deep tilth is produced by early ploughing in the autumn, followed by a cross ploughing later in the year. The second ploughing is done late enough to allow for frost mellowing of the first ploughing and whilst there is still time to obtain similar mellowing of the newly formed furrows. The first dry spell after the beginning of January is the usual time for the operation. The double mellowing then allows the necessary deep tilth to be obtained with the usual tined implements. The fertilisers are applied in the tilth preparation stage. The ridges are then drawn and usually consolidated with ridge rollers, after which drilling of the seed is done. Where sowing is done on the flat only one ploughing is necessary, but this should be early enough to obtain the necessary frost mellowing.

Before the crop is sown the land needs to be cleaned from perennial weeds. This may be done in the autumn by the traditional sets of " wicking " operations, by deep ploughing using skin coulters, or nowadays by the use of either contact or translocatory herbicides. As these crops are usually late sown it has been the custom in some areas to carry out the " wicking " operations in the spring. Whilst the weather in late April and May is often more suitable for these cultivations than that in autumn, the process leads to a drying out of the seed-bed which is to the detriment of germination and establishment.

Farmyard manure, where it is used, is usually ploughed in in the autumn at the present time. Formerly it was often placed in the ridge.

Sowing of swedes begins in the early part of May in the north but may be delayed until the second week in June in the south, where early-sown swedes are specially liable to attacks of mildew if grown on soils which soon become parched in seasons of hot, dry weather.

When the land is ridged it is inconvenient to make the ridges of less width than about 26 in., but on the flat it is not uncommon to drill roots as near as 18 in. from row to row. The usual rate of seeding is 4 lb. per acre, but under ideal seed-bed conditions one pound of seed is ample, and when this smaller amount is used the subsequent singling is greatly facilitated.

Turnips are usually sown about a fortnight after the swedes at 3 lb. per acre, but seeding may continue until the middle or even the end of August.

It is advisable to dress the seed with one of the insecticidal seed-dressings to give the seedlings protection from early attacks of the turnip flea beetle, or " fly " (see p. 435).

Post-drilling Cultivations. Inter-row hoeings should begin as soon as the rows can be seen. When the " fly " is troublesome, dusting or spraying with one of the standard insecticides may be resorted to. Prevailing weather conditions at this time greatly influence the severity of an attack, for with good growing conditions the plants will soon pass the susceptible stage.

Singling usually begins when the first pair of rough leaves is well formed. The actual manner in which the singling is carried out varies in different parts of the country. In many districts singling to one plant is done by hand, in others with a long-handled hoe, whilst more recently the practice has been adopted of using a gapping machine to " bunch " the plants which later can be singled by hand. For success with this method a full plant from one end of the row to the other is essential. Where the crop is to be folded by sheep there is no need to single the bunches as, although the individual roots are relatively small, there is no loss of dry matter yield. Where the crop is to be pulled and carted or chopped for sheep, the larger number of relatively small roots to be handled increases the labour required. Recent developments in the growing of turnips and swedes include the use of precision drills, down-the-row thinners, and graded seed. As a consequence it is now possible to grow good crops either entirely without, or with very reduced, hand singling. This leads to reduced costs and a lessened demand on labour at a critical period.

Harvesting. Swedes are lifted in the autumn for storage in the field where they are grown, or they are carted to the homestead. In favourable districts they are left growing until they can be consumed. When stored, the roots should be topped and tailed and carefully covered with a layer of straw several inches in thickness, and over this a layer of earth at least 6 in. thick should be placed to help in keeping out frost and wet.

Turnips are not usually stored as, being soft, they are easily gnawed by sheep. When required for cattle they are pulled in the same manner as swedes, although they are generally thrown to the stock with the tops left on.

Yield. In good root-growing districts not less than 20 tons per acre of turnips would be considered a reasonable yield, although the average for the country as a whole is in the region of 14 tons per acre. Swedes crop less heavily than turnips, though the weight of dry matter per acre may be about the same. Even where a 20 ton crop is obtained the dry matter yield, at 10 per cent dry matter, is only 2 tons per acre. As the starch equivalent of the dry matter is approximately 60 per cent the yield of starch equivalent is approximately 24 cwt. per acre. To grow and harvest such a crop by traditional methods a total of over 100 man hours per acre may be required. The general trend of opinion in much of the country at the present time is that the crop is a rather expensive source of starch equivalent.

CARROTS

Approximately 30,000 acres of carrots are grown in England and Wales as a direct sale crop.

These roots grow best on light soils free from stones. If grown on heavy land the roots are difficult to lift, and so much soil adheres to them that washing becomes tedious and expensive. Moreover, shapely roots which are easy to market are only obtained on deep, light land. These matters are so important in the case of main crop carrots that the growing of them is confined to the sandlands, the very light silts and the extremely light classes of fen peat. The sandland carrots usually have the superior quality but the yields on the fens are often higher.

As the young plants have very small tops the crop is not suited to weedy land, for in cold seasons the weeds overtake the carrots which are smothered.

Varieties. Varieties of carrot may be divided into three main groups according to shape, Long, Intermediate and Stump-rooted. The long varieties are only suitable for the very deepest soils; the stump-rooted varieties are favoured for the early market and bunching trade, whilst the intermediates are good general-purpose varieties. Well-known varieties within each group are Long Altrincham, St. Valery and Long Surrey ; James' Intermediate and Autumn King ; and Early Nantes and Early Market stump-rooted varieties. The red-cored Chantenay type of carrot is becoming popular in some districts : in these carrots the root is of an even reddish colour throughout, lacking the contrast between yellow core and red outside so characteristic of most carrots. Cattle-feeding carrots such as White Belgian and " cattle " carrots are not very much grown.

Position in Rotation. It is the main crop carrots which are usually grown as large scale farm crops. The early varieties are more frequently grown on specialist horticultural holdings where cloche culture may be used to obtain accelerated earliness. In the latter case they are often followed by late transplanted crops such as a Brassica crop or leeks. In the former case they occupy part of the root break. On the " cash root " producing sandlands they often occupy part of the sugar beet break in a sequence Seeds, Potatoes, Wheat, Sugar Beet plus Carrots, Barley. On the fens they are more commonly grown as a complete break in a four-course sequence of Potatoes, Wheat, Sugar Beet, Carrots. A close sequence of carrots in a cropping system can give rise to trouble with violet root rot and carrot root fly, although control by insecticides of the latter is now possible (see p. 442).

Manuring. Carrots will not grow satisfactorily upon acid soils.

Where acidity occurs suitable applications of lime should be given so that the condition is corrected before the crop is sown. It is generally conceded that an application of farmyard manure given direct to the crop lowers the quality of the root. During the 1939–45 war a number of fertiliser experiments were carried out on the crop. On the experience of these experiments fertiliser rates of 45 units N, 45 units of P_2O_5 and 90 units of K_2O per acre are recommended as suitable. In commercial practice rather higher rates than these are usual. The same experiments showed that the crop also responded to applications of 3 cwt. per acre of agricultural salt and where this is used the potash can be reduced from 90 units to 45 units per acre. Side-band placement of fertilisers has been shown to have no advantage in the carrot crop ; direct contact placement is harmful.

Cultivations and Sowing. The seed-bed needs to be very fine, firm and moist. On the light soils upon which the crop is grown little difficulty is experienced in obtaining the required standard of seed-bed. As with sugar beet, levelness of seed-bed is required to facilitate inter-row cultivations. The seed-bed must be free from perennial weeds.

The seed is sown from March to May on the flat in rows 11–22 in. apart. The narrower drilling is more common on the fens ; on other soils the row width is the same as used for the sugar-beet crop. From 1½–4 lb. of seed per acre are required, but growers try to sow as little as possible in order to obviate the need for singling.

Before sowing, the seed is sometimes well rubbed and mixed with dry sand or ashes, so that it will not clog in the drill, but will fall freely into the drill-rows. It should be harrowed in with light harrows, and not covered with more than an inch of soil.

The carrot crop is usually grown without singling. The early growth of the seedlings is very slow, and formerly a great deal of hand work had to be used to keep it clean. The use of light mineral oil sprays for weed control has reduced the labour required by at least 16 man hours per acre. A pre-emergence application of the oil at the rate of 40 gal. per acre, followed by a post-emergence spray of from 40 to 80 gal. per acre at the four-true-leaf stage, is the usual practice. Inter-row cleaning is carried out with the steerage hoe.

The roots were formerly pulled by hand and the tops were twisted off at the same time. It is now more usual to lift the main crop with a potato harvester but the early carrots are still hand lifted. The main crop is usually lifted from October to December or even later. When not sold direct to the consumer carrots are stored in small heaps protected from the weather with straw and soil. For many markets it is necessary to wash the carrots before sale and for this purpose the large growers have special washing plants. The practice of leaving a portion of the crop *in situ* is becoming increasingly popular. The roots keep better in this way and on lifting in the spring usually command a readier sale than those which have been stored in clamps. The saving in labour is also appreciable. Unfortunately since carrots are susceptible to hard frost the practice involves some risk, and for this reason most growers prefer to secure a portion of the crop under cover.

Yield. The average yield is 10–12 tons per acre, but under very favourable conditions of soil and season upwards of 20 tons per acre may be obtained. The crop is an expensive one to produce in terms of labour. A total of 166 man hours per acre is required where hand lifting, involving 113 man hours, is employed. This figure assumes the use of chemical weed control and that the crop is sold direct from the field without clamping. Where clamping or pieing is involved a further 50 man hours per acre are required. Mechanical harvesting reduces the harvest labour considerably.

FORAGE CROPS

Included in this section is a variety of plants which are consumed in the green state by farm livestock. Many of these plants belong to the Family Cruciferæ, while others form part of the Family Leguminosæ, and are dealt with here because, unlike the clovers, they are usually cultivated by themselves. Maize, which in this country does not ripen its cobs on a farm scale, is used as a forage and silage crop: it is more closely related to the grasses than to the other forage plants mentioned.

BRASSICA CROPS

Marrowstem Kale, Thousand-headed Kale, Rape Kale, Hungry Gap Kale, Kohl-rabi and Cabbage, although very dissimilar in appearance, are nearly related botanically and are all included in the cabbage group, *Brassica oleracea.* This species also embraces a number of important vegetable crops grown for direct human consumption. Brussels sprouts, cauliflower and broccoli as well as the horticultural varieties of cabbage, savoy, kale and kohl-rabi are included under this heading. These are high value crops which are grown both on a field scale and on more specialised horticultural holdings. There are important economic differences between Brassicas grown for forage and as vegetables. In the former case methods of production and utilisation must be such as to provide cheap sources of starch equivalent for stock ; in the latter case the high cash value of the crops allow for techniques of production which are economically not justified for the forage crops. For example, whereas a folded kale crop can be produced and consumed by stock for the expenditure of 40 man hours per acre, the production and harvesting of cabbage and savoy requires 100, autumn cauliflowers 130, and Brussels sprouts 240 man hours per acre. Whereas approximately 460,000 acres of Brassica forage crops (including rape and mustard) are grown, approximately 125,000 acres are grown as vegetable crops. Brassicas as forage crops only are considered below.

Marrowstem Kale is capable of producing very large quantities of greenstuff greatly relished by stock. It is characterised by a thick main stem containing a nutritious pith and bearing large leaves. It thrives on a wide range of conditions but requires generous feeding to produce big yields (Fig. 39).

Thousand-headed Kale is a much-branched plant, growing two, three or more feet in height with numerous plain, uncurled leaves; the plant can withstand more severe winter conditions than marrowstem kale. For this reason it is usually reserved for feeding in the New Year after the marrowstem kale is finished. It is an excellent food for sheep or cattle (Fig. 39).

Rape Kale and Hungry Gap Kale. These are hybrid varieties which find their greatest usefulness in the late spring when the other kales are finished, but the full flush of spring grass is not available for the stock. In April, May, and even as late as June, these varieties send out a profusion of young growth which is extremely valuable for sheep or cattle. Rape kale has a short, thick stem with crinkled leaves. Hungry Gap Kale has a thinner, longer stem with numerous side shoots in the axils of the leaves.

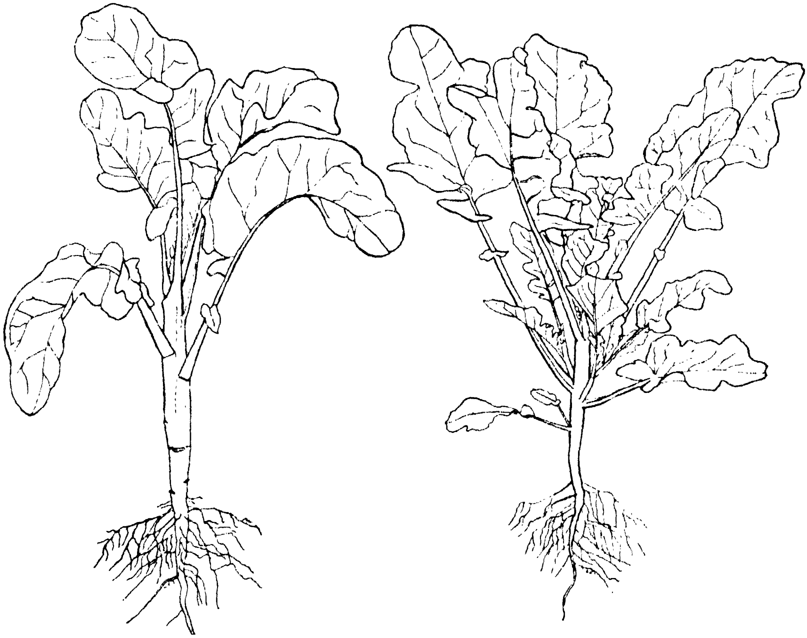


FIG. 39.—MARROW STEM KALE AND THOUSAND-HEADED KALE.

Kohl-rabi is a crop confined mainly to the eastern and south-eastern counties of England. In this plant the stem immediately above the cotyledons or seed leaves becomes much swollen and bears large scars, which are the marks of the junctions of earlier leaves with the stem (Fig. 40). In the comparatively dry eastern counties the cultivation of swedes is particularly difficult owing to their liability to mildew if sown early, and to attacks of turnip fly if drilled later in the season. Moreover, swedes seldom yield well under low rainfall conditions. In these circumstances kohl-rabi provides an excellent substitute, and as it does not suffer severely from drought its cultivation can be extended to lighter soils than those on which it would be possible to grow swedes.

Cabbages are characterised by the shortened main stem and the smooth, glaucous leaves which are closely folded over each other, thus producing a well-compacted, firm head (Fig. 40). In shape, size, colour and hardiness the group furnishes examples of wide differences. Thus, there is the small ox-heart cabbage, the rounder ball-head and the drum-head ; the first, and to a large extent the second, by reason of their more tender and better-flavoured leaves, are used mainly for culinary purposes, whilst the drum-heads provide a valuable green food for stock.

In colour, cabbages vary from various shades of green to red or purple, and in hardiness from forms which can be grown in summer only to those, like the Savoy, which are capable of withstanding severe winter weather.

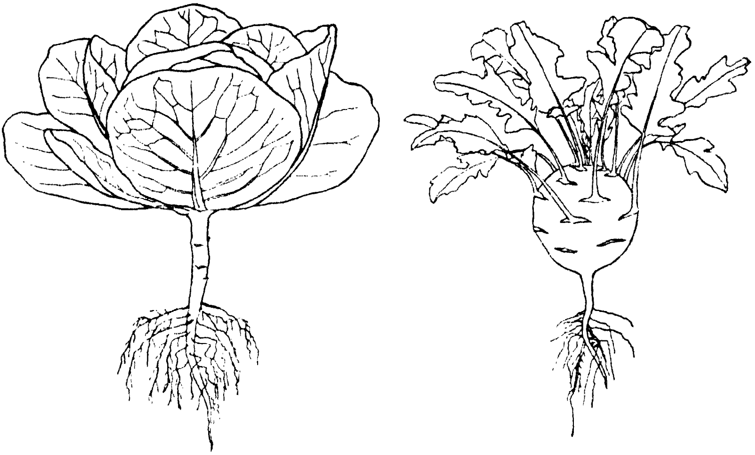


FIG. 40.—CABBAGE AND KOHL-RABI.

Named varieties of each of these Brassica fodder crops exist.

Position in Rotation. All the crops in this group occupy part or the whole of the normal root break on the farm. In addition to being grown in rows, thereby permitting cleaning operations to be carried out in the summer they are, with the exception of kohl-rabi and cabbage, foliage crops which effectively smother out the weeds once they meet in the rows.

Manuring. Brassica crops are gross feeders and liberal manuring is essential if maximum yields are to be obtained. They respond to farmyard manure, and when this is available it may be applied in quantities up to 20 tons per acre. Usually the dung will be applied in the autumn and ploughed in.

The evidence that is available suggests that 100 units of N, 100 units of P_2O_5 and 100 units of K_2O per acre are appropriate under most circumstances. Where 10 tons per acre of farmyard manure are applied the P_2O_5 and K_2O may each be reduced to 50 units per acre. Where kale is taken as the first crop after good ploughed-out grass or leys, 50 units of N will be enough but, particularly after ploughed-out permanent grass, more phosphate may be needed.

Other adjustments of P_2O_5 and K_2O may be needed in the light of soil analysis data. The fertilisers are usually broadcast in the seed-bed; placement 2 in. to the side and 1 in. below the seed gives better early results than broadcasting, but final yields show little difference between the two methods. Direct contact placement of fertiliser and seed can lead to a severe depression of germination. In some cases 50 units of N are top dressed on to the crop before it has met in the row.

Cultivation and Sowing. These crops require cultivations similar to those given to root crops such as turnips and swedes. After a fine seed-bed has been prepared, the seed may be drilled and the young plants thinned as desired. The seed rate is 4 lb. per acre in all cases, but when the plants are grown in a nursery bed 1 lb. of seed will supply enough plants for 1 acre. Transplanting is occasionally used for forage cabbages. It has the advantage of allowing pre-planting cleaning operations to be continued to a later date. Normally it cannot be justified economically for kale, and is a doubtful proposition for cabbage. To obtain the highest yields of dry matter per acre kale needs to be drilled early in April. When this is done the base of the stem becomes woody in the autumn. The woody stem bases are unpalatable to stock and have a reduced digestibility. For this reason kale is often sown in May so that reasonable yields are obtained without undue woodiness. Also with late sowings the crop is not so tall and folding controlled by the electric fence is facilitated. Kale may also be sown broadcast. This is sometimes done late in the season after an early harvested crop such as first early potatoes.

Post-drilling Cultivations. Once the plants are established the subsequent cultural operations are similar to those practised with turnips and swedes—the horse hoes, tractor and hand hoes being kept going until the crop has arrived at a stage when a continuance involves physical damage to the plants. For cabbages, singling is necessary to obtain a full development of the head. With kale, singling, gapping or leaving the drill unthinned are each common practices. It has been shown that there is no advantage to be gained in terms of dry matter yield by reducing the plant population by either singling or gapping the crop, provided weeds are not a problem. The unthinned crop does, however, have a larger stem : leaf ratio, a lower protein content and a higher fibre content. On the other hand it is cheaper to produce.

The relatively inexpensive mechanical gapping would appear to be a useful compromise. This assumes that the crop is either folded or harvested with the forage harvester. Where it is hand cut and carted there is a considerable advantage in having a low population of large plants obtained as a result of singling. In the case of Thousand-headed kale, singling or gapping increases the yield of secondary shoot which is a valuable part of the crop when consumed after the turn of the year.

Harvesting and Yield. Kohl-rabi, which makes excellent feeding for sheep or cattle, may be folded off but it can also be lifted and stored like swedes. It is more resistant to frost than swedes, and if necessary can be left much longer without lifting. Its keeping qualities are remarkably good and the yield varies from 15 to 25 tons per acre.

The kales may be folded off by cattle or sheep or the crop may be cut and carted home for feeding fresh to housed cattle. The advent of the flail type of forage harvester has greatly facilitated the cutting and carting of the crop. Whereas kale folded by cattle, using an electric fence, may be produced and used for the expenditure of 40 man hours per acre, at least 100 are needed where hand cutting and carting is the harvest method. Marrow-stem kale also makes excellent silage, which is very useful for feeding in late winter when the crops have lost their freshness and have become fibrous and of lower feeding value. The average yield is 20–30 tons per acre. These gross crop yields will give almost 2 to 3 tons of starch equivalent per acre which, if folded, represent one of the cheapest sources of starch equivalent for winter feeding. Marrow-stem kale gives the largest yields per acre, followed by Thousand-headed kale, with Rape kale and Hungry Gap kale giving smaller yields.

Cabbages are invariably cut and carted home for feeding to stock in yards or out-wintering on grass. Under good soil and climatic conditions and with liberal manuring, the cabbage crop can yield 40–50 tons per acre and is then regarded as one of the most useful crops for feeding to stock.

Rape. This is a valuable forage crop, especially for sheep. Rape is a leafy, succulent plant very similar to a swede except that no bulb is formed. It grows to a height of 2–3 ft. and may be cultivated as a main crop or used for catch cropping. Sown in April it is ready for grazing off in July and August, and will yield 12–15 tons per acre of greenstuff. The varieties in general use are The Giant and Essex Dwarf; the former is usually regarded as more suitable for poorer and lighter classes of soil and the latter for the richer soils.

Sowing is invariably done on the flat and the seed may be drilled or broadcast. The latter is the usual procedure and 10–12 lb. of seed per acre are required; if drilled, 4 lb. of seed are ample. Following broadcasting no further cultivations are necessary and, indeed, the manner of seeding makes such impossible. On account of its rapid leaf development rape will smother weeds most effectively. When land is being sown to grass without a cereal cover crop, 2 lb. of rape are frequently included in the seeds mixture to act as a nurse crop and provide early grazing for the stock.

As a catch crop following early potatoes or peas, rape is also very useful. After early potatoes harrowing and rolling are all the operations necessary for the preparation of the seed-bed, but after peas it may be necessary to plough, or at least disc harrow thoroughly, and then harrow and roll to obtain the necessary fineness of seed-bed.

MUSTARD

Two species of mustard are cultivated in England, namely White Mustard (*Brassica alba*) and Black Mustard (*B. juncea*). The tall-growing species known as Brown or Black Mustard (*B. nigra*) which was previously grown for condiment has been virtually replaced by *B. juncea* and persists now largely as a weed on land on which it was previously cultivated. All these species are annuals and in many respects closely resemble the crops dealt with already in this group.

White mustard is largely grown as a catch crop in the same manner as rape : it differs from the latter in respect to its susceptibility to frost. A mixture of rape and mustard in equal parts is frequently grown for sheep feed, whilst in some parts mustard is sown after early potatoes for the purpose of green manuring. The rate of sowing is about 20 lb. per acre. White mustard is also cultivated for its seed in the Eastern Counties ; the seed forms one of the components of mustard flour for condiment.

The pungency of condiment mustard is imparted by Black mustard which contains as much as 22 per cent of volatile oil. *B. juncea* is a more adaptable plant than was *B. nigra* in that although it will give a larger yield on more fertile soils it can be grown successfully on quite light soils. It is also shorter than *B. nigra*—growing up to 3 ft. 6 in. high—and holds its seed better and can therefore be harvested by combine. The crop responds well to liberal dressings of nitrogen but phosphate and potash are only required where a known deficiency exists. The crop is frequently grown after a straw crop and helps to lengthen the rotations. Seedrate is 4–5 lb. per acre in drills 7 in.–21 in. apart, sown early in March.

Harvesting takes place in early August. The crop may be cut with a binder and stacked ; windrowed with a pea-cutter and subsequently picked up by the combine ; or even combined direct. It should not be cut until the seed is almost ripe and the seeds are a rich brown colour. Seed yields vary between 10 and 20 cwt. per acre.

LEGUMINOUS FORAGE CROPS

Vetches or Tares. This crop is used principally to provide keep for sheep, and green fodder for cattle and horses in spring. Tares are extremely useful to include in a mixture with oats and peas or beans for making into hay or silage, whilst in some cases this mixture may be allowed to ripen to provide grain which can be ground into a balanced meal for dairy cows. Vetches generally follow a white straw crop of some kind, and in light land districts are often grown as a catch crop.

The plant is characterised by slender, square, trailing stems frequently as much as 6 ft. in length ; the leaves are pinnate with numerous obovate leaflets, and the leaf stalk usually terminates in a simple or branched tendril. The flowers, which arise either singly or in pairs on short stalks, or as racemes in the axils of the leaves, may be blue or purple in colour. Because of the weak, trailing stems, tares are more frequently grown in mixture with a cereal which then acts as a support (Fig. 41).

Tares do not exhibit a strong partiality to any particular class of soil ; they may be grown on stiff clays if adequately drained, and equally well on sandy soils, provided the supply of moisture is sufficient and there is no shortage of lime. In their ability to thrive on

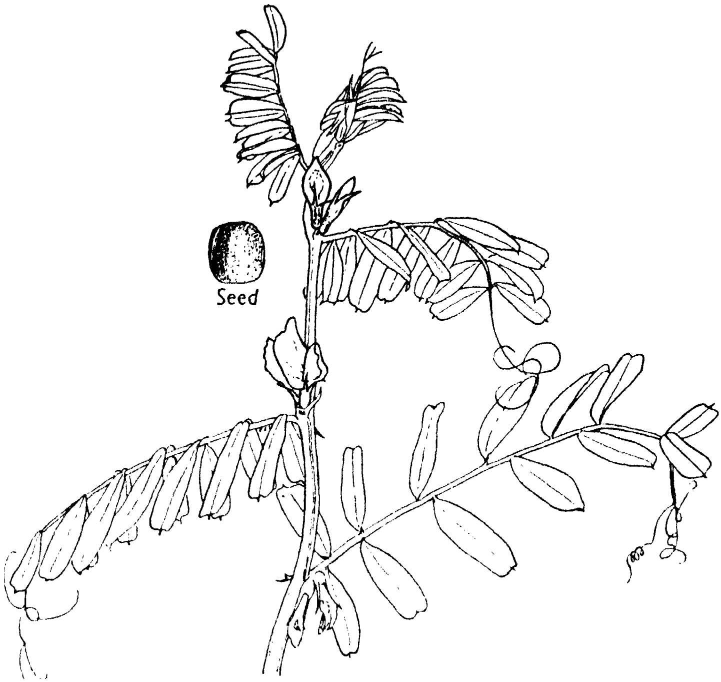


FIG. 41.—CULTIVATED VETCH (*Vicia sativa*).

poor soils they constitute a valuable means of increasing the stock-carrying capacity of this type of land.

Varieties. In the British Isles the most widely grown variety is the Common Vetch (*Vicia sativa*) which is subdivided into spring and winter sorts. These are similar plants botanically, but differ in their ability to survive the winter. In some districts the Goar or summer vetch is grown extensively and this resembles the common vetch in its flower characteristics, but is a stronger growing plant with larger leaves, stems and pods. The Goar is apparently as hardy as the common vetch, but arrives at full growth somewhat earlier. By sowing portions of the land devoted to vetches with the common variety and also with Goar, the period for cutting the silage crop can be extended without incurring loss in the nutritive value of the silage due to over-ripening and the attendant development of fibre.

Position in Rotation. The crop does not occupy a regular position in the crop rotation, but when grown as a pure crop it is the usual practice to sow after a cereal. When used in mixture with cereals to cut for silage the crop may replace roots completely, in which case as soon as the crop is removed in July the opportunity is taken to bastard fallow in readiness for the next crop.

Manuring. When the crop is grown for seed nitrogenous manures should be used sparingly, if at all, for they over-stimulate the production of haulm. The same objection does not apply in the case of crops intended for soiling or for silage. In the absence of precise experimental data on fertilisers for vetches it can be assumed that the requirements will be similar to those for peas and beans. That is to say, 20–40 units of P_2O_5 and 40–80 units of K_2O. The larger dressings are only recommended for crops which are intended to be grown on soils which are relatively low in these nutrients. Where the crop is grown in admixture with oats as a silage crop, N to the extent of 40–60 units should be used in addition.

Cultivation and Sowing. Following a cereal crop the land is simply ploughed, fertilised and disc harrowed, and the seed drilled at the rate of 1¼–1½ cwt. per acre from September onwards. Provided they are sufficiently well covered to prevent depredation by birds, it is inadvisable to bury the seed too deeply; about 1 in. is the ideal depth.

When grown in mixture winter oats should be used with winter vetches, or spring oats with spring vetches. The following mixtures have been used widely with considerable success:

(*a*)	Winter oats	140 lb. per acre.
	Winter tares	56 ,, ,, ,,
	Winter beans	28 ,, ,, ,,
(*b*)	Spring oats.	140 ,, ,, ,,
	Spring tares	56 ,, ,, ,,
	Peas	28 ,, ,, ,,

In some cases vetches are sown on stubbles which are merely cultivated and harrowed until a sufficient tilth is secured, and the land harrowed again to cover the seed—a practice, however, that can only be recommended when the stubbles are reasonably clean.

Harvesting. By reason of their trailing stems, once the crop is sown little can be done in the way of subsequent cultivations. In districts possessing a suitable climate vetches are made into hay, but they require a long period of dry weather to cure the succulent stems and may suffer considerable damage if subjected to heavy rain. For hay or silage purposes the crop should be cut when still in flower, for with the development of seed the stem becomes more fibrous and less valuable for feeding. The yield of hay varies from 1½ to 3 tons per acre.

When grown for seed production the most satisfactory method is to include a small quantity of beans as a support for the vetches. The beans can be readily separated from the vetches by riddling after threshing. The yield of seed varies from 10 to 15 cwt. per acre.

For folding with sheep the autumn-sown crops will be ready the following May and the spring-sown later in the summer, according to the date of sowing.

Lucerne. Lucerne is a perennial plant known in some countries as Alfalfa, and botanically as *Medicago sativa* (Fig. 42). It is a very important forage crop used mainly for cutting purposes although with proper treatment it can also be grazed. Its chief characteristic is its deep root system by means of which it has the capacity to remain productive under severe conditions of drought.

In some respects lucerne is an exacting crop, for although it will thrive on a fairly wide range of soils, one essential feature with all of them must be an adequate supply of lime. The land must be well drained and, if not of high natural fertility, then care must be taken to ensure adequate supplies of plant nutrients. Clean ground is also essential, this being important in the early phases of establishment of the lucerne stand. Under reasonable conditions lucerne will give a succession of crops throughout the growing season, resulting in three to four cuts annually and a total dry matter yield of at least four tons per acre. This production can be sustained for five or six years or even longer : when finally ploughed up, lucerne is extremely valuable in maintaining arable soils in good physical condition.

The acreage devoted to lucerne in Britain is comparatively small, some 85,000 acres at the present time, and this is largely restricted to the lower rainfall areas in the eastern and southern counties. Some effort has been made to extend the area grown to some western and northern counties. Difficulty arises, however, from the fact that the more normal grass and clover seeds mixtures do so well under the higher rainfall conditions in these parts of the country and are less exacting in their management, so that lucerne growing spreads only slowly if at all.

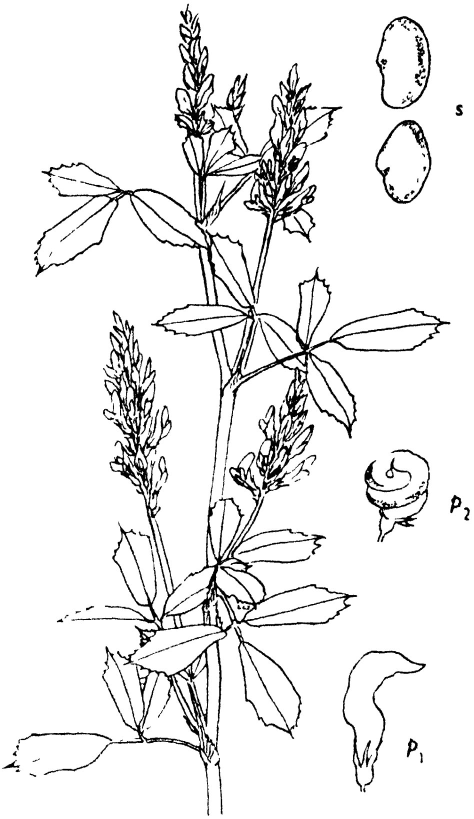


FIG. 42.—LUCERNE (*Medicago sativa*).
s, seed. p_1, newly formed pod. p_2, mature spirally coiled pod.

In its early period of establishment from seed, lucerne develop slowly and does not attain its full production capacity for some two or three years after sowing. Conditions of establishment must therefore be of a high order in terms of soil tilth, freedom from weeds and availability of plant nutrients. Given these conditions the young lucerne seedlings, which are extremely vulnerable to competition from other plants, will get away to a quick start and so avoid any initial check to growth. The introduction of a method for inoculating lucerne seed with an appropriate strain of bacteria capable of effecting the development of nitrogen-fixation nodules on the young seedling root system has done much to ensure better establishment of lucerne on soils deficient in such bacteria (see p. 397). The cost of inoculating the seed is very small and the method simple to apply under farm conditions.

Varieties. Since 1945 the lucerne varieties used in Britain have become more numerous than was the case previously. These varieties are now classified in accordance with the time they begin active growth in the spring. Four main groups are recognised, of which the first two are most important agriculturally :

(1) *Early Varieties*—Du Puits, Chartainvilliers, Eynsford, Socheville and W.268.
(2) *Mid-Season Varieties*—Provence, Marais, Poitou and Marlborough.
(3) & (4) *Late and Extra-Late Varieties*—Grimm, Ladak and Rhizoma.

Seed Rates. Lucerne may be sown in a number of ways. Pure stands of lucerne alone may be grown, in which case 12–14 lb. per acre of seed sown in close drills is the rate of seeding. These pure stands are liable to become weed infested, particularly on the heavier soils : to avoid this, as well as to assist in easier conservation as hay or silage, it is customary to sow a companion grass. To ensure the minimum of competition from the grass its rate of seeding must be kept fairly low : 2–3 lb. per acre using cocksfoot and timothy and 4–5 lb. per acre using meadow fescue. Lucerne/grass mixtures may also be sown in alternate drills, 10–12 in. apart ; here the rate of seeding of lucerne may be reduced to some 4–6 lb. per acre, and the grasses, which no longer compete with the lucerne with this method of sowing, can be increased in seeding rate by a few pounds if necessary.

Manuring. Lucerne demands an adequate supply of lime throughout the whole soil profile. Care must be taken to ensure that lime is present in the lower soil reaches so that when the deep penetrating roots reach these levels their progress is not retarded and the growth of the plant affected by acid conditions. Initial supplies of phosphate and potash are required, particularly of potash on the lighter soils. In these latter circumstances supplies of potash are again essential in the later years. Seedling establishment may, in some situations, be improved by the incorporation of a small amount of nitrogen in the seed-bed fertiliser dressing, while backward stands later on may also benefit from a judicious top-dressing of a nitrogenous fertiliser.

Sowing. The time of sowing will depend on the preceding crop and the state of preparation and cleanliness of the land. Perennial weeds, particularly those of a creeping type, should be removed before sowing, and where annual weeds are present it is advisable to reduce their incidence by encouraging them to germinate before the final pre-sowing cultivations are carried out. Many of these weeds in young lucerne stands can now be controlled by the application of selective herbicides based on 2,4-DB. These must be applied after the lucerne has developed its first trifoliate leaf, and preferably between this time and the appearance of the fourth trifoliate leaf.

The seeds may be sown in spring from late March to early May or sowing may be left until late July. Later sowings than this are not possible as winter frosts may severely damage and kill seedlings not properly established and developed. Spring seeding may be under a nurse crop or direct; in the former method a stiff-strawed, early-maturing variety of spring wheat or barley is preferable. July seedings are direct sown.

One particular pest that must be controlled in the seeding stages to prevent failure of the lucerne stand is the Pea and Bean weevil (*Sitona spp*) (see p. 436). This may be done by applying DDT as a dust or spray in the early seedling stages as soon as any leaf damage is observed.

Management. After seeding the management of a lucerne stand should be as lax as possible in terms of mowing and grazing for the first eighteen months or so. This will allow the stand to become firmly established, and once a strong plant with a good root system has developed, the lucerne will give consistent yields over a number of years. Sown under a cover crop in the spring, the lucerne in the stubble should be allowed to develop during the autumn and die back in the winter without being cut or grazed. This is also the treatment for a July sown seeding, whilst a direct sown spring seeding should be cut over once at a height of 6–8 in. during the summer to control weed growth. The stand may then grow on unchecked into the autumn and die back in the winter. Under such treatment lucerne stands will develop strong root systems by the first harvest year, when two cuts may be taken at the early flower bud stage of growth. Subsequent growth in the late summer and autumn of this year should be allowed to grow on until growth ceases, after which it may be grazed. In subsequent harvest years, three to four cuts may be taken, but here again as much autumn rest as possible should be given to maintain a strong plant.

Lucerne may be grazed rather than cut, particularly the growth following the first cut of the season. When grazing, it is essential to use the electric fence to control the period of grazing. This should not be prolonged over too many days to avoid grazing the new growth.

Lucerne hay is best made on tripods. In this way the leaf, which is the more nutritious part of the plant, is prevented from shattering and the hay ensuing will be of high quality. Lucerne may also be conserved as silage, and here a grass companion is useful to allow proper fermentation of the silage and to avoid some degree of unpalatability that may occur with lucerne silage.

In an established stand, heavy harrowing when the lucerne plant is dormant during the winter is of advantage in controlling both broad-leaved weeds and in checking the growth of any companion grass. Harrowing will also open up the stand and result in a more vigorous growth of the individual lucerne plants.

Sainfoin occupies a limited acreage both as a hay and a pasture crop, more particularly in the eastern and southern counties of England, especially on chalk land. The root is long and strongly developed and capable of penetrating to considerable depths. Sainfoin may be included in "seeds" mixtures but is more commonly sown as a pure crop (Fig. 43).

Varieties. There are two commercial varieties in general use: the Common sainfoin which may be left down for five to seven years or even longer, and the Giant or double-cut sainfoin which usually occupies the ground for one year only. Common sainfoin is better suited to medium soils whilst the giant type does well on light land. There is a number of local strains of common and giant sainfoin which appear to be superior to the ordinary commercial strains.

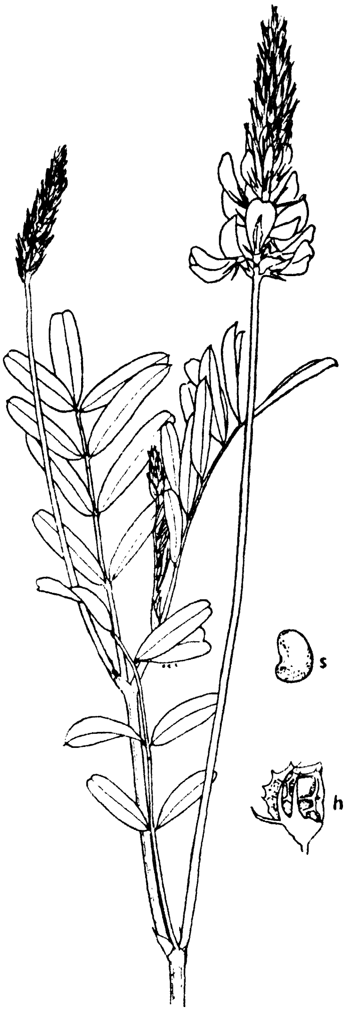


FIG. 43.—SAINFOIN (*Onobrychis sativa*). *s*, seed. *h*, husk.

Manuring and Cultivation. Lime is essential for sainfoin which, like lucerne, needs phosphate and potash in addition. The manurial recommendations for lucerne apply equally to sainfoin. Sainfoin is usually sown with a cereal, which on light land is invariably barley, and on heavy land, wheat. In the former case, and especially in dry districts, it is usual to drill the sainfoin at the same time as the barley, but at right angles to the rows of that crop. As with other smaller seeded leguminous crops, a firm seed-bed and a fine tilth are essential. The seed rate is 56 lb. per acre for milled seed and 100 lb. per acre when seed with the husk still on is used. This is sown from February to May, usually in rows about 7 in. apart and not deeper than 1 in.

From giant sainfoin the average yield of hay is about 30 cwt. per acre, whilst after the second year yields of double that amount may be obtained from common sainfoin.

Trifolium, also called Crimson Clover, is an erect, tall growing, annual clover whose cultivation is confined to the south and south-east of England because of its susceptibility to frost. There are early, late and medium strains of the crimson form, and a late white-flowered variety (Fig. 44).

The crop is chiefly grown as a catch crop, being sown in the autumn on corn stubbles which have been lightly cultivated, usually with disc harrows, and to which a light dressing of phosphatic fertiliser may be applied. The seed rate is 20–24 lb. per acre, which is usually simply broadcast and harrowed in.

The crop is fed off by sheep the following April and May in sequence, according to the strain sown, care being taken to consume it before it becomes advanced in growth and woody. At this stage the flowers become hairy and may cause hair-balls to form in the intestines of the stock.

Lupins. The cultivation of lupins is largely restricted to poor light land in the eastern counties. The fact that the crop does well on land deficient in lime and humus is made use of by growing this crop for ploughing in as green manure, for which purpose it is ideally suitable.

Three types of lupin are available, white-, yellow- and blue-flowered, the blue proving the most reliable. In recent years the Sweet Lupin, from which the bitter, toxic principle has been eliminated, has been introduced as a forage crop, but so far it has not been cultivated on a very large scale.

Place in Rotation. On poor light land the crop may constitute part of the rotation, being grown in sequence with rye, potatoes and buckwheat. It may also be grown as a catch crop for green manuring after early potatoes or peas or a bastard fallow. Lupins do best on land that is distinctly acid, and free lime in the soil appears to be a disadvantage.

Cultivation and Sowing. Ploughing followed by harrowing and rolling is all that is likely to be necessary to prepare the seed-bed on typical lupin land. Seeding takes place in April, 60–120 lb. of seed, according to variety, drilled in rows 7 in. or 20 in. apart. Broadcasting is quite satisfactory. In most cases nothing in the way of after-cultivation is likely to be carried out, though the crop may be horse hoed if necessary.

Harvesting. For seed purposes the crop must be cut before it is fully mature or losses due to shedding may be considerable. Frequently the crop is cut with a binder, even though the canvases are subject to considerable wear, for when the crop is cut with a reaper the strong spines on the ends of seed pods make tying very unpleasant. It may be cut and harvested loose. After fielding until quite fit the crop is carted and threshed in a comparable manner to beans.

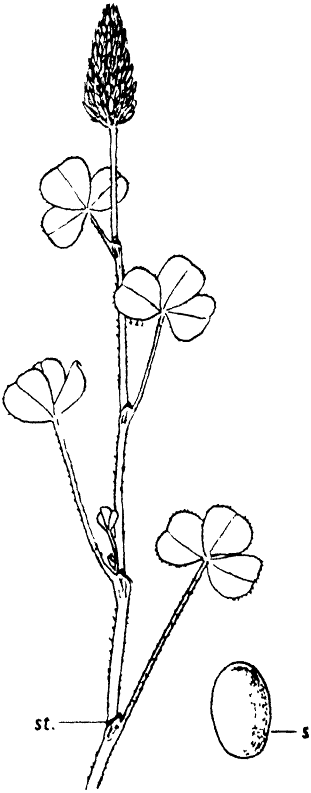


FIG. 44.—TRIFOLIUM (*Trifolium incarnatum*).
s, seed. *st.*, blunt stipule.

When a big crop of lupins is ploughed in for green manure it is usually necessary to roll it down first and to attach a drag chain to the plough beam to ensure complete burial of the plants.

Yield. The yield of seed is from 12 to 18 cwt. per acre.

MISCELLANEOUS CROPS

Maize. Maize is grown extensively in America and Canada for silage purposes, and the recent introduction of early-maturing hybrid varieties, forage harvesters and suitable herbicides has revived interest in this country in the use of the crop for silage. It is essentially a sun-loving crop, flourishing during periods of drought, and hence it is valuable as a silage, forage or even a grain crop in the dry eastern and south-eastern counties. The newer varieties have resulted in a wider distribution of the crop, particularly in the Midlands, but even so, it is unsuitable for the North of England. It is susceptible to frost and more suited to early soils ; heavy soils are not suitable for it.

Varieties. Over 200 varieties have been tested by the N.I.A.B. in recent years, and of these some 24 are now on their list of recommended varieties. These are classified on their origin, maturity and relative yields of dry matter per acre, the following being examples.

1. Early group and suitable for grain production in S. England—Inra ; Prior II.
2. Medium/early silage group—Caldera 402 ; Wisconsin 270 ; C.I.V. 7.
3. Medium ,, ,, —Warwick 277 ; Kingscrost K.C.3 ; Orla 266.
4. Medium/late ,, ,, —Maize King V ; Pioneer 383.
5. Green feeding group not suitable for silage—White Horse Tooth.

Manuring. Generous manuring is essential in order to give the rapidity of growth necessary to ensure a full crop. A suitable fertiliser dressing would be about 100 units of nitrogen, 50 units of phosphate and 100 units of potash per acre. This should be worked into the seed-bed. The crop responds well to dung application, and when it is applied the above fertiliser dressing can be reduced accordingly. When the crop is well up, 20–40 units of nitrogen will often give a ready response from the crop, but it may suffer from a temporary scorching effect as a result.

Cultivation and Sowing. Maize requires a clean seed-bed. Suitable autumn stubble cleaning operations are followed by the application of dung, when available, and the land is then cross ploughed and left in the furrows over winter to weather : with the aid of harrows and rollers in the spring the requisite fine tilth is obtained. During the cultivation operations the fertilisers can be applied and mixed in with the surface soil. Sowing takes place when the danger of frost is past, which is about late April in the south and mid-May in the Midlands. The seed, which should be dressed with an appropriate seed dressing, is sown at the rate of 30–35 lb. per acre at a depth of 2–3 in., usually with a corn drill : a precision drill gives a better spaced seed distribution. Row width varies from 14 in. upwards, but a minimum width of 28 in. is necessary when the crop is to be harvested with special maize harvesting machinery. For maximum yields an average plant population of 9 per square yard should be aimed at. Bird, and particularly rook, damage at the time of germination and emergence is often troublesome and the main cause of crop failures. At sowing time no seed should be left exposed, and whenever possible the crop should be sited near the homestead. In cases of a determined bird attack the crop can be protected by black cotton or string 4 ft. above the ground and attached to poles set out at 8 yards apart. This, however, prevents inter-row cultivation which should commence as soon as the rows can be seen. Mechanical and hand weeding can often be eliminated by the application of 2 lb. (3 lb. on medium or heavy soils) of 50 per cent wettable simazine in 20–100 gallons of water per acre which should be applied during the first seven days after sowing. Sufficient surface soil moisture is necessary for the latter treatment to be effective : 2,4-D at 1 lb. acid equivalent in 20 gallons of water per acre applied at the four-leaf stage can also give an adequate weed control.

Harvesting. Cutting for forage begins in August, particularly in a dry year when the crop is fed green on bare pastures or in the byre. For ensiling, the crop is cut during late September/early October when the cobs have reached the cheesy stage ; ensiling must be completed before the first severe frost. Harvesting is most easily carried out with a maize harvester, or chopper-type forage harvester fitted with a maize harvesting attachment, blowing into trailers. Care should be taken to ensure that the cobs, which contain a high percentage of the food value of the crop, are not wasted.

Yield. On land in good heart and in a favourable season, 30 tons per acre of green crop is not uncommon : 20–25 tons per acre may be regarded as a satisfactory yield. It is not difficult to ensile maize when the material is cut with a forage harvester, and the high starch content helps fermentation. In feeding value maize closely resembles kale and cabbage, but on the larger farms where bigger acreages are grown it may be cheaper per unit of food. Its high starch content makes it particularly suitable for fattening cattle who can consume efficiently up to about 80 lb. of silage per day per adult animal. For milking cows up to 60–70 lb. per head per day may be fed, supplemented with a suitably balanced concentrated ration.

Linseed. The linseed plant (*Linum usitatissimum*) may be grown either for the production of its seed, which contains a high proportion of oil, or for flax fibre. In either case the crop succeeds best in districts with a low rainfall and warm climate, and when grown on kindly friable loam soils which are well drained but never likely to dry out. The crop is unable to withstand drought owing to its shallow rooting habit of growth (Fig. 45). Good results may be obtained on light land provided there is an adequate humus content, or on heavy soils when conditions favour the production of a fine seed-bed.

Varieties. For seed production, Royal and Valuta are suitable, and can be sown early. For late sowings, Dakotor and Redwing should be chosen : the former is considerably more productive, but a day or two later in ripening. Flax is grown only on contract for processing factories and the seed is supplied direct by the factory to the growers. Since about 1950, the cultivation of flax in the British Isles has virtually ceased.

Position in Rotation. Provided the land is clean and extremes of poverty or richness are avoided, linseed may occupy any convenient place in the rotation. As a general rule it will follow a straw crop: it may be used as a nurse crop for seeds, for which purpose it is excellent, since there is little foliage to smother the young grass and clover seedlings and the crop is harvested early in the season.

Manuring. In both cases the crop is generally grown on reserves of plant food in the soil, and little return can be expected from any fertiliser except nitrogen. Not more than 30 units of nitrogen are needed as a rule.

Cultivation and Sowing. A clean, fine, firm seed-bed is essential and to this end all the cultivation operations should be directed.

Seeding can take place as soon as soil and climatic conditions are favourable in the spring. For seed production the linseed can be sown broadcast at 100 lb. per acre or drilled at 40–60 lb., but for fibre production drilling is always preferable as this gives more even maturity at pulling time. The seed should not be buried deeply, ½-1 in. being ample in most cases, followed by a light harrowing and rolling.

Harvesting. When grown for seed the crop should be cut when the seed in the ripest capsules is plump and a shiny pale-brown colour. Most crops show very uneven ripening and if left until all the seed heads are ripe a good deal of shedding is likely to take place. The sheaves should be small to facilitate drying and should not be carted until perfectly dry. Careful adjustment of the threshing drum is essential to secure clean working. The straw is useless for feeding or for bedding, but the chaff is a very valuable food for making linseed jelly or feeding direct.

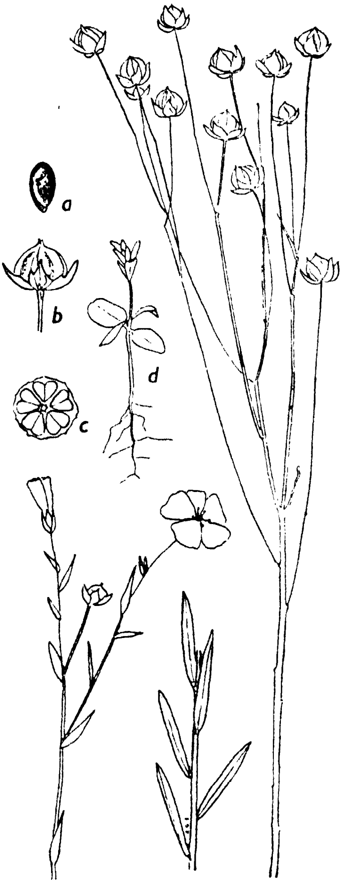


FIG. 45.—LINSEED (*Linum usitatissimum*).

a, seed. *b*, seed capsule or boll. *c*, boll in transverse section. *d*, seedling.

Yield. Seed crops usually average 10 cwt. per acre, with exceptional crops in the region of a ton. An average yield of flax is about 2–2½ tons per acre with no more than 4–5 cwt. of seed.

GROWING ROOT CROPS FOR SEED

In recent years the production of seed of root and other crops has developed very considerably, and this country is no longer so dependent upon imported seed as it used to be. The outstanding example is the sugar beet crop. Before 1939 most of the sugar beet seed sown here came from abroad, but by 1945 home production of seed was sufficient to supply all requirements and leave a small excess for export.

Mangel and Sugar Beet. The production of seed from these two crops is so similar that they may be considered together. The plants are biennial under normal methods of cultivation, growth during two seasons (or more accurately, exposure to low temperature) being necessary for the formation of flowers and seed. Seed is sown from July to mid-August in rows 9–12 in. apart in seed-beds. One acre of seed-bed, sown with 30 lb. of seed, provides enough stecklings (or young plants) for planting out 10 acres. Stecklings can be transplanted from the seed-bed in autumn or in early spring. Each method has its advantages and disadvantages. Autumn planting leads to early growth in spring, which may be important in a dry season, but plants left in the seed-bed over winter are better protected from hard weather and, when planting is done in spring, a full plant can be assured. Spring planting also tends to the formation of bushy plants. Planting can be done by hand or by a mechanical planter. The rows are 2–3 ft. apart, and the stecklings in the rows 12–24 in. apart. It is important to avoid planting with the tip of the root turned up ; if necessary the roots must be trimmed. If the land is in good heart, as after potatoes, further manuring is not necessary, otherwise 40–60 units of N, 40–60 units of P_2O_5 and 60–120 units of K_2O per acre may be applied.

Suitable isolation must be provided for these seed crops because mangels, sugar beet, garden beet, sea-kale beet and spinach beet will all cross-pollinate. At least 1,000 yd. should separate seed crops of this group. In the chief seed-producing areas of the eastern counties special zoning schemes are in operation to facilitate isolation.

Inter-row cultivations and hand hoeing where necessary are needed to keep down weeds. The leading shoot is topped, or cut off with a knife, usually when the plants are about 18 in. high, some 3–6 in. being removed. Topping causes the plant to bush out and produce several flower-bearing stems. Harvesting takes place when about half the seed has turned brown ; it is inadvisable to delay harvesting until all the seed has ripened because of the losses in shedding. The crop is cut with hooks, tied into sheaves and stooked. Sheets are used freely when carrying to the rick to collect shed seed. Ricks should be narrow and well ventilated. The average yield is 12 cwt. of seed per acre.

Brassica Crops. Swedes, turnips, kale and rape are all grown for seed in very much the same way. They are all biennial, requiring growth in two seasons to complete the life cycle. Isolation must be very carefully considered, and crops should be separated from other brassica crops by at least 1,000 yards.

There are two methods of obtaining plants, by direct drilling or by transplanting ; usually only swedes are transplanted. Swede seed is drilled in the field during mid-July to mid-August at the rate of 2–4 lb. per acre. Turnip seed is drilled from mid-August to mid-September at 2–4 lb. per acre. Kale and rape are drilled in June and early July at 4 lb. per acre. The width apart of the rows varies with the equipment available, and may be from 18 to 30 in. In spring the plants are thinned out to 10–15 in., and an application made of 40–60 units of nitrogen. Kale is frequently left unthinned. For transplanting, swede seed is sown in seed-beds, 1½–2½ lb. producing enough plants for an acre. Transplanting takes place from November to early March, according to weather and labour conditions. Hand labour or a mechanical transplanter can be used, the stecklings being set out 9–18 in. apart. Horse and hand hoeing are done as required, and a certain amount of earthing up may be carried out to support the plants.

Crops can be harvested with a hook, but the binder makes a good job of most crops. The sheaves are stooked, and while crops can be threshed out in the field in favourable weather, the more usual plan is to make a rick and thresh later. Careful handling at all stages is necessary, as the ripe pods shatter very easily.

The average yield per acre of swede seed is 8 cwt., of turnips 10 cwt., of kale 7 cwt., of rape 10 cwt.

Rape for Oil Production. Various types of rape are sometimes grown in this country to produce seed from which oil is extracted, but it is a limited market. Depending upon the variety, rape is sown in spring or late summer in rows 7–8 in. or 16 18 in. apart. The crop requires adequate lime and 60 units of nitrogen in the seed-bed. It is harvested in July/August with a binder and then threshed or combined direct. The yield of seed is about 15 cwt. per acre and it contains about 45 per cent oil.

Chapter XI

THE CONSTITUENTS, ESTABLISHMENT AND MANAGEMENT OF GRASSLAND

In Britain the flora of the cultivated grasslands, namely, meadows and pastures, is composed mainly of grasses and clovers. Although about one hundred species of these are commonly found, less than twenty can be considered of much agricultural importance. These for the most part are capable of growing under a wide range of both soil and climatic conditions, though few of them are found in much abundance outside the limits of enclosed land.

FACTORS INFLUENCING THE FLORA OF GRASSLAND

Soil. Some plants show a sufficiently marked preference for the conditions obtaining on, for instance, chalky or clay soils to make them the dominant species of the associations occurring in such situations, but this does not imply that they will not be found on gravelly or loamy soils. All soils, indeed, tend to carry their more or less distinctive grass flora when the fields remain down for a number of years. For instance, a very distinctive flora occurs on soils overlying the Chalk on which the smaller fescues and crested dogstail thrive ; and again on the sour soils of the Coal Measures and Millstone Grit formations where bent, Yorkshire fog, mat grass and wavy hair grass form the bulk of the vegetation. These natural associations have, generally speaking, a very low productive capacity, and the essence of good grassland husbandry is to cultivate the more productive species. The soils which are especially favourable for the development of good grassland are the well-drained loams, preferably those on the heavy side. Good second-class grassland occurs on the clay soils of the Midlands and Eastern Counties, whilst sandy and gravelly soils are characterised by producing a thin, low-yielding type of turf. On chalk and limestone soils the grassland is best fitted for grazing, the herbage being short and sweet and well liked by stock.

Management. Apart from the natural tendency to form a certain type of sward according to soil and climate, the flora depends upon the use made of grassland. If a field is mown year by year and only the aftermath grazed, the flora tends to differ from that of a field which is systematically grazed. The taller grasses which form the bulk of the hay crop shade the dwarfer species and the white clover sufficiently to check their growth and finally to suppress them. The herbage thus tends to consist of the stronger growing species such as perennial ryegrass and cocksfoot. Where grazing is practised these vigorous growers are kept under control and other grasses, together with white clover, have a better chance of developing. Because of this a common method of management is to mow and graze in alternate years in order to maintain some balance between the species. In many parts, however, meadows and pastures are kept separately and treated in the same manner year after year. The modern technique of grassland management stipulates either a rotational system of management to include both hay and grazing, or the provision of leys composed of mixtures of grasses and clovers specially compounded for these two methods of utilisation.

Climate. The productivity of grassland, whether meadow or pasture, depends more on climate than any other single factor. As a result of the dependence of the grasses on an abundant rainfall, the grasslands of Britain are concentrated in the west and north, being better suited to and more productive under the wetter climatic conditions prevailing in these parts as compared with the drier eastern and southern areas. Deficiencies in the rainfall may, however, be offset by higher water tables which provide a continuously moist root range. The plants then grow steadily throughout the spring, summer and autumn, and provide the grazier with an unusual uniformity of production. An example of this is to be found in the so-called " marshes " of East Anglia where rich grazings occur that continue growth even during a dry summer on account of readily available soil water.

Such conditions can also be secured by irrigation. This, in essence, was the system used in the water meadows of Wiltshire and Dorset, although the practice has by now fallen into disuse. Irrigation by artificial means is, however, used on an ever-increasing scale coupled with systems for combining irrigation with that of the disposal in a semi-liquid form of dung and urine from stock housing. Where these methods of providing pasture growth are applied the yield of herbage can be increased some 50–100 per cent during the growing season. The application of the water must however be done systematically, for water in excess of soil-holding capacity is detrimental to the growth of the better grasses. Under waterlogged conditions tussock grass, rushes and sedges are the dominant species in the sward.

The main bulk of the root system of grasses does not range deeply in the soil and the depth to which it penetrates is determined largely by the soil's physical condition. On badly aerated clay soils most of the roots will be found in the top 2 in., whilst in loams and the lighter types of soil they may extend their range to a depth of 6 in. This relatively shallow rooting habit is characteristic of all of the grass and clover species of agricultural importance, and none of them is capable of making much use of the moisture present in the deeper layers of the soil. Drought must always present the grassland farmer with serious feeding problems, but its effect can be offset to some degree by adopting husbandry techniques in terms of suitable seeds mixtures, fertiliser usage and, where practicable, irrigation.

Season. The rate of growth of herbage plants in British grasslands is dependent on the seasons. At the beginning of the farming year, in October, it slows down and, except in mild seasons, it practically ceases with the coming of winter. In severe weather the foliage may die off almost completely. There are differences, though, in the hardiness of the various grasses, but practically the only permanent grasses resistant to winter burning are perennial ryegrass, crested dogstail and rough stalked meadow grass. Even with these, however, care must be taken not to allow excessive leaf growth to go through into the winter as this renders the plant more susceptible to frost damage. After lying dormant through the winter, growth begins again in the spring, the various grasses starting into growth at different periods. With the coming of warmer weather, and especially of an ample rainfall, the rate of growth accelerates, reaching a peak from mid-May to mid-June, according to season and district. At this stage most of the species, if ungrazed, begin to flower. Growth then slows down and the subsequent production of aftermath depends largely upon climatic conditions and the level of fertility. The variability of grassland from season to season constitutes the grazier's chief difficulty, for he must estimate at the beginning of the season the head of livestock that the pastures can carry, and so control the grazing that the plants are eaten when at their maximum nutritive value, which is when the leaves are some 4–6 in. in length and when sunlight and water are freely available to promote sugar formation and mineral uptake.

THE CHARACTERISTICS OF GRASSES

Two of the most important characteristics of grasses are first their fibrous, adventitious roots, and second their habit of *tillering*, or producing new shoots at about ground level.

Tillering. The production of numerous fibrous roots means that grasses have greater powers of recovery after injury than have plants with a main tap root. If a tap root is severed or broken it may mean death to the plant, but grasses are often stimulated by root injuries to produce yet more fibrous roots. That is one of the reasons why severe harrowing of old pastures may have beneficial results.

The tillering capacity of grasses is obviously of great economic importance. A grass with a single shoot can hardly be as productive as a grass which forms numerous side shoots ; a grass which tillers profusely will cover the ground much more rapidly than a grass which tillers less freely. This is one of the reasons why some of the new varieties of perennial ryegrass such as Aberystwyth S.23 or Melle pasture will form closer swards at a low rate of seeding than will pastures seeded with varieties having a poorer tiller production capacity. Some grasses which tiller freely tend to form tufts, for example cocksfoot, but if the tillers are kept grazed or mown this tuftiness is masked and the herbage in the sward remains even. In a grass such as tussock or tufted hair grass, however, the tillers are so unpalatable to grazing stock that they are neglected and huge tussocks standing well above ground may be developed. Some grasses, like smooth-stalked meadow grass, do not tiller in the accepted sense of the word, but spread by underground stems or rhizomes ; the habit of growth is matted rather than tufted. Any bud-bearing portion of a rhizome which is broken off the plant can start another independent plant. It is this characteristic which makes couch grass such a pest in arable land (Fig. 47).

General Structure. The general structure of a grass is shown in Fig. 46. The aerial parts of a grass consist of the leaves, stem and inflorescence or ear. The leaf is made up of a sheath, which clasps round the stem, and a blade. At the junction of a sheath and blade are two structures. First the *ligule*, a delicate, colourless membrane pressed close to the stem, and second the *auricles*, or claws. The claws have already been mentioned in describing the shoot structure of wheat (see p. 215), and they are of considerable value in recognising the grasses. The shape of the blade and its appearance in cross section are also useful aids to identification (Fig. 48).

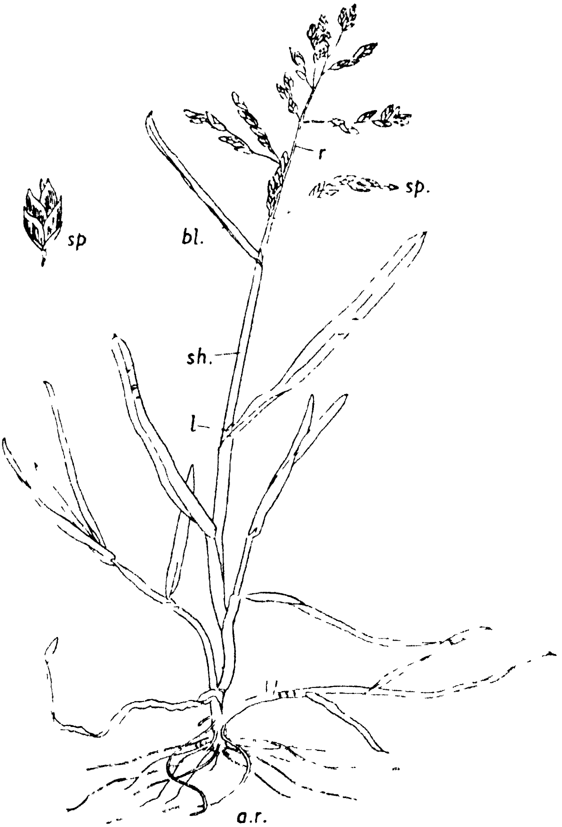


FIG. 46.—A TYPICAL GRASS—ANNUAL MEADOW GRASS (*Poa annua*).
a.r., adventitious root system. *l*, ligule. *sh.*, leaf sheath. *bl.*, leaf blade. *r.* rachis. *sp.*, spikelet.

The inflorescence, or ear, is of two kinds. Usually it is a branching ear, or *panicle*, with the individual spikelets on short or long branches, as in meadow fescue or rough stalked meadow grass. Sometimes the spikelets are set direct upon the *rachis* or stem forming a *spike* as in perennial ryegrass or timothy. Each spikelet has two chaffy coverings called *glumes* within which is a short stalk, the *rachilla*, upon which are situated the florets. Each floret has its own chaffy coverings, the *paleae*, or *pales*, enclosing the ovary and stamens. The so-called seed of grasses consists of the ripe ovary (grain or caryopsis) enclosed within

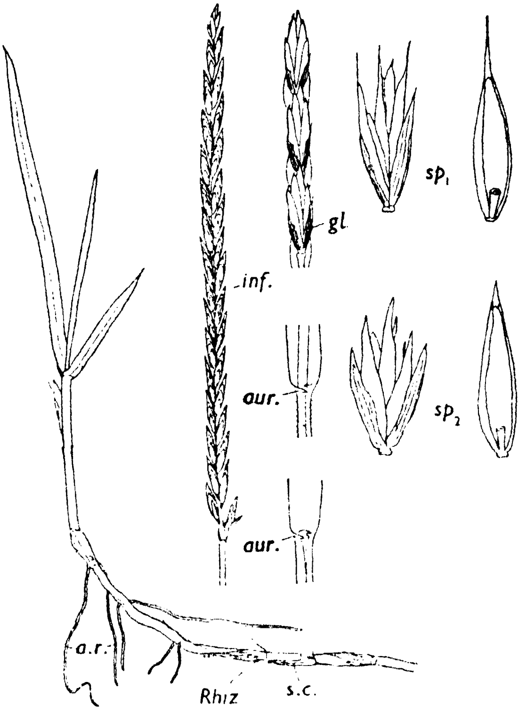


Fig. 47.—Couch Grass (*Agropyron repens*).

Rhiz, rhizome. *a.r.*, adventitious roots. *sc.*, scale leaves. *inf.*, ear. *gl.*, glumes. *aur.*, auricles. *sp*$_1$, *sp*$_2$, spikelet and seed of the awned and awnless forms.

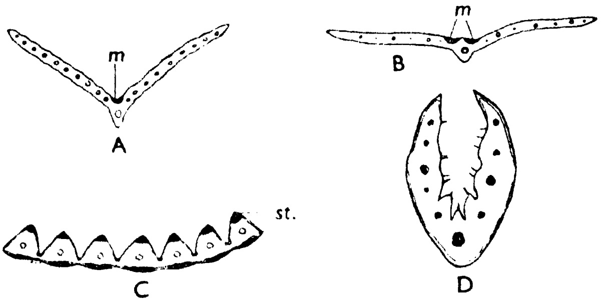


Fig. 48.—Leaf Structure in Grasses.

Transverse sections of A, Cocksfoot ; B, Smooth-stalked Meadow Grass ; C, Tussock Grass D, Sheep's Fescue.

m, motor cells. *st.*, strengthening tissue.

the pales, and sometimes the glumes as well. This is a very fortunate arrangement because the grains of the grasses are all very similar, but the chaffy portions differ widely in appearance, and so enable us to recognise the commercial seed of grasses fairly easily.

SPECIES USED IN AGRICULTURE

The more important species of grasses used in seeds mixtures are described below.

Perennial Ryegrass (*Lolium perenne*) is one of the most widely distributed species in Britain and is usually the dominant grass in first-class pastures (Fig. 49). It is a lasting perennial on good soils, but on light land, especially in dry districts, it tends to die out after a few years. Perennial ryegrass has a long growing season, is palatable and responds to manurial treatment. It stands cutting and grazing very well, but when grown in association with other grasses it has a suppressive action on them and also on the companion clovers.

The seed is cheap, rarely contaminated with weed seeds and, when fresh, has a satisfactory germinating capacity. This, after a normal seed harvest, is generally about 85 90 per cent. A high bushel weight (28 lb.) is usually a good index of the quality of a seed sample. A light bushel weight indicates that the seed is only partially developed, either through immaturity at harvest or through feeble development of the crop. To much importance, however, must not be attached to a high bushel weight. It is no index of the value of the plant which grows from the seed.

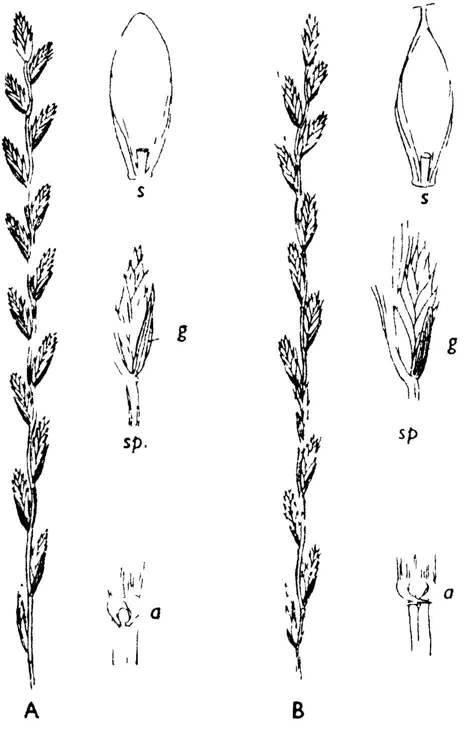


FIG. 49. - THE RYE GRASSES (*Lolium spp.*): A, PERENNIAL RYEGRASS (*Lolium perenne*); B, ITALIAN RYEGRASS (*L. multiflorum*)

s, seed. *sp*, spikelet. *g*, glume. *a*, auricles.

Perennial ryegrass forms the basis of most seeds mixtures in general use for both long and short duration leys. The young plants grow rapidly, and under favourable conditions produce a good yield of herbage in their first year, but reach their maximum productivity by the second year. Most of the commercial seed comes from Ireland and Ayrshire. A number of bred varieties is also available, the more important being the following: Kentish, a leafy, somewhat late but persistent variety produced from old pastures; New Zealand Certified Mother, and Aberystwyth S.24, which are leafy persistent types early in spring growth; Aberystwyth S.23, a very leafy, persistent, high-tillering and late-flowering pasture variety; Aberystwyth S.101, which is similar to S.23 though not so late in beginning growth in the spring, but requiring rather better soil conditions. Other varieties of perennial ryegrass are now becoming available on the commercial market in Britain, for example, Melle pasture, Heraf and Mommersteeg pasture.

Italian Ryegrass (*Lolium multiflorum* var. *italicum*) is a biennial and on moist, fertile soils, especially such as those irrigated with sewage, it is capable of producing a greater bulk of herbage than any other species of grass which can be cultivated in this country. The yields under the more ordinary conditions of farming are also high, and in addition the grass is remarkably winter-green and makes good growth early in the spring (Fig. 49B). It is this characteristic that is now being increasingly exploited for the provision of " early bite " in the spring, particularly in the feeding of dairy cows. It is a first-class, short-duration grazing plant, which recovers rapidly after defoliation.

It is readily established from seed, and the plants rapidly reach their maximum productivity ; for this reason Italian ryegrass must be used sparingly in mixtures which include the slower-growing grasses and clovers because its vigorous growth tends to stifle them. Under these conditions the seed rate should seldom exceed 3–4 lb. per acre. Reliable seed with a germination capacity of 85–95 per cent can always be obtained. The main bulk of seed in the past has been of Irish origin, but the Aberystwyth S.22 variety is rapidly gaining favour on account of its leafiness and persistency. Bred varieties from other countries which are suited to British conditions are also commercially available.

Westerwolds ryegrass (*L. multiflorum* var. *Westerwoldicum*) may be described as an annual form of Italian ryegrass. It establishes rapidly from seed, runs to head quickly and is stemmy in growth. Improved varieties are now commercially available which retain the rapid growth characteristics and annual form, but which are a little more leafy and persistent than the unimproved varieties. Westerwolds ryegrass can be useful in providing a hay crop in the year of seeding under conditions where for some reason or other a seeds mixture sown for this purpose the previous year has failed to become established.

Cocksfoot (*Dactylis glomerata*) is a grass capable of producing a good bulk of fodder, although possibly not of the highest feeding quality. It is widely distributed and of particular value on light, sandy soils in regions of low rainfall where it thrives better than other species. Its growth begins fairly early in the spring, depending upon the variety and the management in the previous autumn. The young shoots in the spring are very palatable and care must be taken not to overgraze at this time. Understocking when the plant is growing rapidly must, however, be avoided, for the foliage tends to become harsh and unpalatable and the plants, especially when widely spaced, grow into rough, compact tufts which may unprofitably occupy a large proportion of the grazing surface. Some varieties of cocksfoot " burn " badly in the winter and these should, wherever practicable, be grazed down cleanly in the autumn. Other varieties not quite so susceptible to " burn " are used for winter grass production on account of the capacity of cocksfoot to make good growth in the autumn. On thin, light land where ryegrass tends to die out after the second year, cocksfoot should be included in the seeds mixture, for it is under such conditions that its greatest value will be found.

Commercial supplies of seed come mainly from Denmark and New Zealand. The Danish type of cocksfoot is characterised by its earliness, whilst New Zealand stock (Akaroa) is more persistent and more leafy, but begins growth later in the spring. A considerable amount of seed is produced in Britain, chiefly in the Eastern Counties. Three varieties coming from the Welsh Plant Breeding Station, Aberystwyth, have been available on the market for some time. These are : Aberystwyth S.26, a persistent, leafy variety which is rather later than the Danish but more wintergreen ; Aberystwyth S.37, an improved hay variety, and Aberystwyth S.143, a pasture type which stands up well to heavy stocking by sheep and which is later in spring growth. Other imported bred varieties now available are Tardus II, Trifolium II and Roskilde II, all of which are similar to Aberystwyth S.37 in type (Fig. 50).

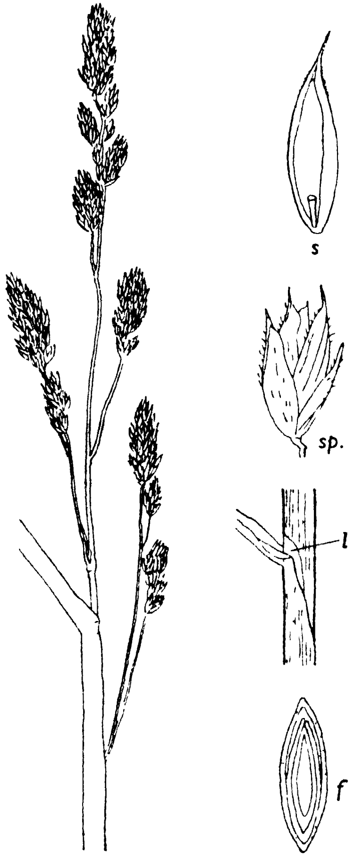


Fig. 50.—Cocksfoot (*Dactylis glomerata*).

s, seed. *sp.*, spikelet. *l*, ligule. *f*, section of the flattened shoot.

Timothy (*Phleum pratense*) thrives best on deep fertile loams and clays. When sown on light soils in dry districts it may fail to establish or, if established, fails to persist. It reaches its maximum productivity by the first harvest year ; it is late in flowering and its characteristic broad, bluish-green leaves are produced rather late in the spring so that the palatable growth made at this time helps to supplement pasture growth as this declines in other grasses. Autumn growth does not produce any bulk of herbage, but the plant remains green into the winter (Fig. 51). As a hay plant timothy excels, and well-made timothy hay always commands a high price and a ready market, for it is especially valuable for horses. Under suitable soil and climatic conditions this grass may be sown alone to form a timothy meadow or, as is more general at the present time, it is sown with meadow fescue as these two grasses grow extremely well together. Timothy is one of the most palatable grasses and care must be taken to avoid it being overgrazed on this account.

Commercial supplies of seed are abundant and cheap and come mainly from Canada, the U.S.A. and Scotland. These are stemmy in habit of growth and not persistent under grazing. Bred varieties are available which are leafy and persistent and do not deteriorate as rapidly when grazed. These include Aberystwyth S.51, a leafy hay type; Aberystwyth S.48, a very useful leafy plant persistent under reasonably intensive grazing, and Aberystwyth S.50 (*Phleum nodosum*), an extreme pasture type that is suitable for severe grazing conditions and for use under close mowing in top fruit orchards when these are grassed down. Swedish Omnia is a foreign bred variety now on the British market, and this is suited to conditions where S.48 is used. Some seed firms in Britain have also developed useful varieties on these lines.

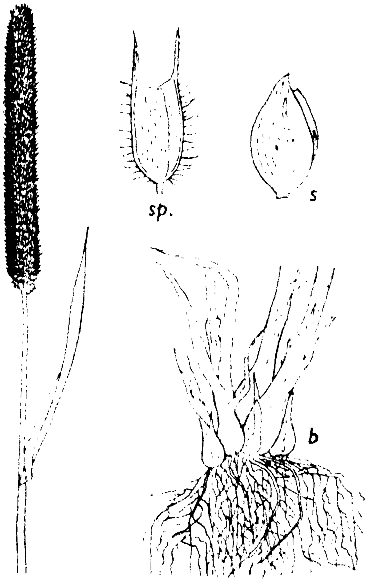


FIG. 51.—TIMOTHY (*Phleum pratense*).

s, seed. *sp*, spikelet. *b*, swollen base of stems.

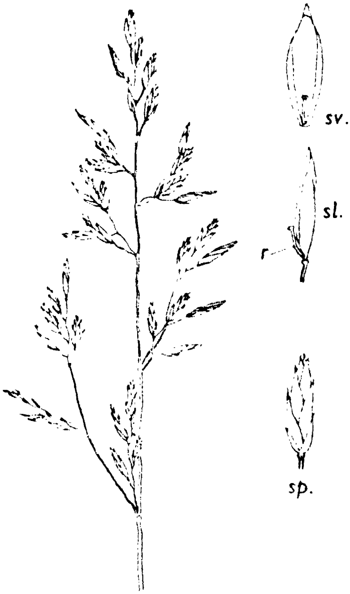


FIG. 52.—MEADOW FESCUE (*Festuca pratensis*).

sv., seed (ventral view). *sl.*, seed (lateral view). *r*, rachilla. *sp.*, spikelet.

Meadow Fescue (*Festuca pratensis*) is often found in some of the best pastures in the country, especially on deep, fertile soils and well-drained clays (Fig. 52). It is an almost universal constituent of the herbage of water meadows where, to a great extent, it takes the place of perennial ryegrass. Until fairly recently the valuable potentialities of this grass were not appreciated, because it was usually sown in mixtures containing more aggressive grasses with which it was unable to compete. In consequence it was looked upon as a grass not readily established from seed; sown by itself, however, or in company with a less aggressive grass such as timothy, it has been shown to be one of our most valuable agricultural grasses. It is extremely palatable and grows well in company with white clover as well as timothy. It has a mid-season habit of growth, making only a little autumn growth, and this in turn tends to " burn " if excess of leaf is left on the plant during the winter.

Commercial seed supplies are mainly from the U.S.A. and Denmark, while bred varieties such as Aberystwyth S.215 and S.53 are also available. S.215 is an early, leafy type while S.53 is a pasture variety—later in spring growth. Other bred varieties produced by plant breeders in Denmark, Sweden and Holland are Trifolium II and Mimer, both early varieties ; and Mommersteeg pasture which is similar in habit of growth to S.53.

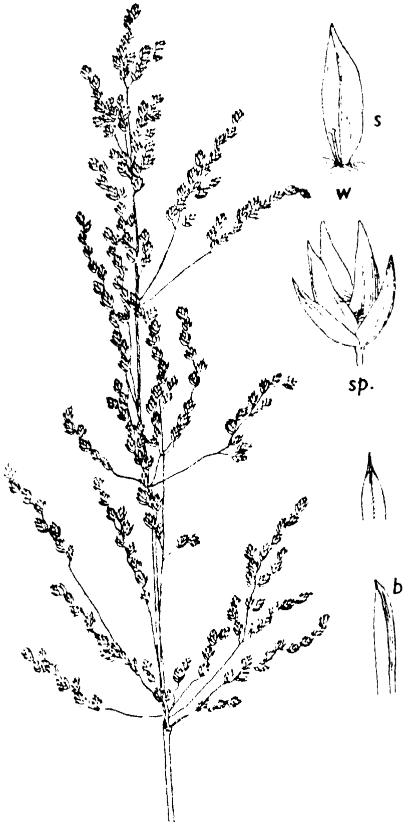


FIG. 53.—ROUGH-STALKED MEADOW GRASS (*Poa trivialis*).

s, seed. *w*, web of hairs. *sp*, spikelet. *b*, " boat-shaped " tip of leaf.

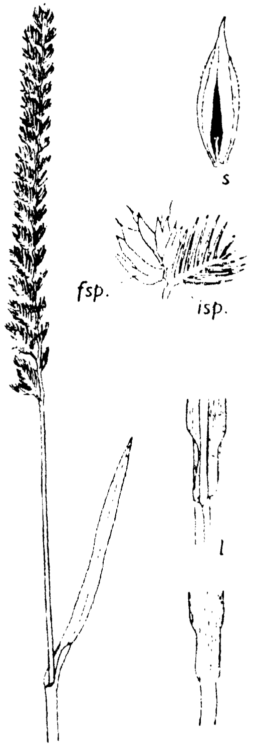


FIG. 54.—CRESTED DOGSTAIL (*Cynosurus cristatus*).

s, seed. *fsp*, fertile spikelet. *isp*, infertile spikelet. *l*, leaf.

Tall Fescue (*Festuca arundinacea*). In Britain this grass can be found growing under natural conditions ranging from moist soils in low-lying meadows to the drier soils of the chalk and sands. Its chief characteristic is its capacity to grow in the late autumn, winter and early spring. Until recently, however, this feature has not been exploited for grazing purposes on account of the coarse nature of the plant and its consequent lack of palatability. Improvements are being made in this respect, and varieties are being bred which will lead to this grass being more widely used, particularly for winter grazing purposes and for " early bite " in the spring. Its slow establishment from seed can be largely overcome by growing it in drills 10–21 in. apart, and under these conditions it will produce a good bulk of leafy fodder.

Commercial supplies of seed are obtained from the U.S.A. and Holland. Aberystwyth S.170 is a bred variety, more leafy and palatable than those available from commercial sources.

Rough Stalked Meadow Grass (*Poa trivialis*) is the most valuable of all the " bottom " or close-growing grasses, its short runners and fine, close growth being ideal for the formation of a closely knit sward (Fig. 53). The foliage is fairly abundant, relished by all kinds of stock and produced over a long season. The grass is widely distributed, and though generally to be found in the greatest abundance under somewhat moist conditions of rich loams or water meadows, it does fairly well on poor soils provided that the rainfall is adequate. On light soils it is apt to burn out in dry weather and disappear completely. In such conditions its place should be taken by the rhizomatous Smooth-stalked Meadow Grass (*Poa pratensis*).

Both meadow grasses are essentially pasture plants and better suited for long leys than for temporary leys, since they grow comparatively slowly and take some three years to reach the stage of maximum development. Practically the whole of the seed is imported, the bulk of it coming from Denmark and the United States. As the seeds are small the inclusion of 1–2 lb. per acre in any seeds mixture is usually ample.

Crested Dogstail (*Cynosurus cristatus*) is a widely distributed grass thriving not only on fertile loams but also on heavy clays and on the light soils overlying the chalk (Fig. 54). Its yield of herbage is small compared with that of perennial ryegrass and because the seed heads are not consumed by stock it is a prolific self-seeder and may become the dominant species in a sward. For this reason its chief value is on the poorer classes of soil where the more productive species fail to attain their full output, and where its winter-green character can be put to good use by sheep.

THE CHARACTERISTICS OF CLOVERS

For farm purposes no sward can be considered complete unless it contains a proportion of clovers. There are two reasons for this, the more important one being the power that clovers possess of removing nitrogen from the air via the root nodule bacteria (see p. 396). The results of this behaviour are first that the foliage of clovers is relatively richer in protein than that of grasses, and second that a crop of clovers leaves a residue of nitrogen in the soil in the same way as a crop of beans and peas enriches the soil. Another reason for including clovers in a ley is the relative richness of some members in mineral salts. White clover contains proportionately more calcium and magnesium, for example, than most grasses. This may be an important factor in preventing symptoms of mineral deficiency in the livestock grazing or feeding on such herbage.

Clovers are dicotyledonous plants whose seedlings are provided with tap roots and whose cotyledons, or seed leaves, are brought above ground. The first true leaf is always a simple one, but later leaves are trifoliate. The root nodules begin to develop at about the same time as the first leaves, and the nodules themselves vary in shape and position from species to species.

One useful structure for recognising clovers is the *stipule*, a small modified leaf found in pairs at the base of the leaf stalks. In alsike clover the tip of the stipule tapers gradually; in red clover it terminates abruptly in a sharp point (Figs. 55, 57). The growth habit of clovers is also variable. Red and alsike clovers are erect growing, with basal shoots or tillers. White clover spreads by stolons, a habit which is of great importance in turf formation.

Of the true clovers only three are used to any extent in the formation of leys, namely red, white and alsike clovers.

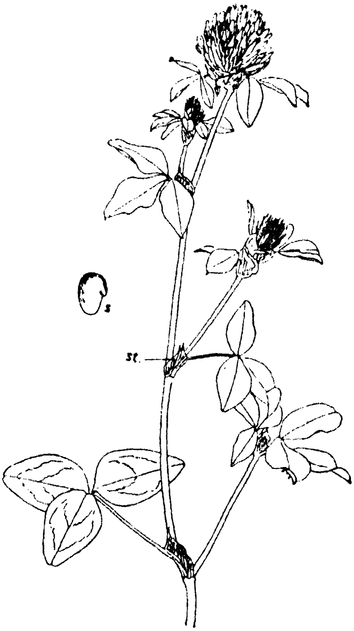


Fig. 55.—Red Clover (*Trifolium pratense*). *S. seed. st, stipule.*

Red Clover (*Trifolium pratense*). The history of the origin of red clover, as of so many agricultural crops, is obscure, but there are good reasons for thinking that it is not a native of the British Isles. It was the subject of considerable notice in the agricultural literature of the sixteenth century, especially on the Continent, and there is a strong probability that it was introduced into England from there by Sir Richard Weston, or reached here as a result of his strong advocacy. Its value for stock feeding, and as a preparation for wheat, soon became recognised, and it has been used mainly for this purpose from then on. At the present time its use in this respect is declining, particularly with the advent of fertilisers containing nitrogen. It is almost certain that the original stocks contained a large number of varieties, and the crop as now grown is remarkable for a large number of localised types. These differ not so much botanically as in features such as persistency, resistance to disease, time and duration of growth and the bulk of the produce (Fig. 55).

Three types of red clover are of interest agriculturally: Early-flowering red clover, also called Broad red clover or Double-cut red clover; Late-flowering or Single-cut red clover; and the Extra-late flowering red clover.

Broad red clover is about a fortnight earlier in flowering than late-flowering red, and in its first harvest year—the year after seeding—it will give a cut of hay or silage followed by an aftermath for cutting or ploughing-in or for seed purposes. It makes little recovery growth after this and is therefore mainly used as the chief constituent of one-year leys, or as a part contribution in the first year to leys of longer duration. Commercial seed stocks are mainly of local varieties such as Essex and Suffolk ; some may be imported from Canada or New Zealand, while somewhat later flowering and persistent Broad red types are to be found in such varieties as Vale of Clwyd, Aberystwyth S.151 and Dorset Marl.

The late-flowering red clovers tiller more abundantly and as a type are more persistent and hardier than Broad red. In seasonal growth they give a good cut of hay but little aftermath, and they remain active in growth for two to three years. They are less susceptible to clover sickness (*Sclerotinia trifoliorum*) than the early-flowering types and are generally sown as part of a general seeds mixture of long duration. Local varieties are available, but considerable quantities of Canadian seed, particularly of a variety called Altaswede, have been brought in to Britain in recent years.

The extra-late-flowering red clovers are late in spring growth, have a high tillering capacity and are persistent. They are, therefore, used under conditions where the fields will be grazed fairly intensively, particularly by sheep in the winter and early spring, followed by a hay cut. This form of management may take place over a number of years. Seed is available as New Zealand Montgomery, but the bulk of the supply is of home origin, namely, Montgomery, Cornish Marl and Aberystwyth S.123.

White Clover (*Trifolium repens*). It is probable that white clover, like red clover, found its way into England from the Low Countries. The plant is characterised by its creeping habit ; the runners or stolons root freely, and when sown with grasses in a seeds mixture they knit the grasses together to form a close sward. It is essentially a grazing plant (Fig. 56).

There are two distinct types of white clover in agricultural use in Britain, the large-leaved or *Giant white*, and the smaller-leaved *Wild white*. The chief distinguishing feature between these two types is that of size, both of the leaf and of the plant as a whole. They also differ in persistency—the large-leaved types are less persistent, being productive from one to five years, while wild white clovers are truly perennial. In any one season the bulk of herbage growth from the large-leaved types will be greater than that from wild white.

The large-leaved white clovers are the varieties Aberystwyth S.100, Kersey and New Zealand Mother. Aberystwyth S.100 is relatively persistent and continues in full growth for at least three years, and on soils of good fertility for as long as five to seven years. New Zealand Certified Mother closely resembles S.100. Kersey white clover is a variety built up from plants selected out of a pasture near the village of Kersey in Suffolk. Under Eastern Counties conditions it does well in seeds mixtures, being persistent and palatable to stock. The large-leaved white clovers are particularly useful in establishing leys of from 2 to 5 years' duration. They cover the ground very quickly, and under good management are very productive. Their vigorous growth has made possible the ultra-simple grass seeds mixtures of the one grass-one clover type (see p. 316).

Wild white clover has smaller leaves and thinner, more branching stolons than the giant white clovers. It is consequently less productive, but on the other hand is more persistent. Although an excellent grazing plant, wild white clover should not be allowed to dominate a pasture, for it is less productive at certain seasons of the year than the grasses.

The best known strains are Kentish and S.184 wild white clovers. Certain local strains of wild white clover have good reputations, and special arrangements have been made to preserve their characteristics (see p. 331).

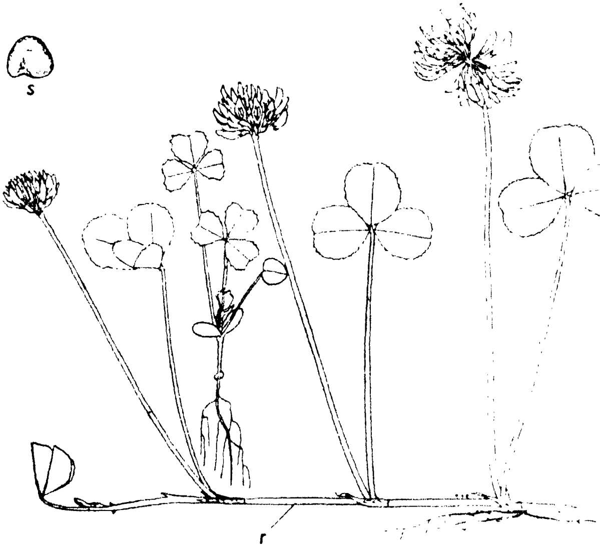


Fig. 56.—White Clover (*Trifolium repens*).

s, seed. *r*, runner or stolon.

Although white clover has a strong tap root it also roots freely at the nodes of the prostrate runners. The plant responds very markedly to phosphatic fertilisers, particularly basic slag. As a turf former it has no equal. Some of the nitrogen which it accumulates from the air in its root nodules is released in the soil and stimulates the surrounding grasses.

Alsike Clover (*Trifolium hybridum*) is similar in habit of growth to late-flowering red clover although not so persistent (Fig. 57). It has the advantage of being a good deal hardier and less susceptible to soil acidity and clover sickness, and hence is generally included in mixtures for sowing on land where there is reason to believe that red clover may be a doubtful proposition. It is an excellent companion plant for timothy in hay mixtures. The supplies of seed are almost wholly Canadian.

Trefoil (*Medicago lupulina*) is an annual plant related to the true clovers, found in abundance on chalk and other soils containing much lime. It does not contribute greatly to the bulk of material obtained from seeds either for hay or grazing, but it is useful for providing an early bite for sheep on chalk land. It is a ready self-seeder and consequently almost functions as a perennial unless grazed before it sets seed. If sown too generously in mixtures it may have a smothering influence on the other species. Supplies of seed are chiefly English.

Miscellaneous Herbs. In association with the grasses and clovers, one frequently finds in a pasture or meadow, especially when these have been down for a number of years, miscellaneous plants like ribgrass or plantain, chicory, yarrow and burnet. The specific value of these plants is not fully known, but farmers in many grassland districts are firm believers in them, even to the point of including them in seeds mixtures. It is known that they have a high mineral content and are well relished by stock which will seek them out in a pasture. It is also believed, though not proved, that they counteract scouring in stock grazing a lush pasture. They are all deep rooting and capable of withstanding drought, and on thin upland soils ribgrass may be the only plant contributing to the keep of the stock during a prolonged period of dry weather. There are grounds for suggesting that such disorders as hypomagnesaemia in grazing stock may be reduced in incidence by the inclusion of herbs in the diet by way of pasturing or in the silage and hay feed. The chief drawback to the use of these plants is the amount of space they occupy in relation to the amount of keep they provide. For this reason they may be sown alone in a narrow " herb strip " across the field where the stock can help themselves, and where the herbs can have freedom for development yet are restricted to a reasonable area of land.

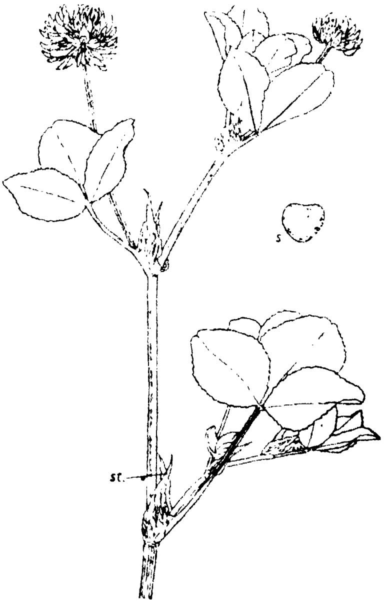


FIG. 57.—ALSIKE CLOVER (*Trifolium hybridum*).
s, seed. *st.*, stipule.

THE ESTABLISHMENT OF GRASSLAND

Arable land left to itself will in time grass itself down, often with a considerable degree of success which at first would appear to indicate that no special care is needed in the establishment of grassland. That this is far from the truth was amply demonstrated, prior to the agricultural revolution which took place with the outbreak of the second world war, by the derelict grassland resulting from the tumbledown methods of laying arable land down to grass following the 1914–18 war. When arable land tumbles down to grass the immediate flora is derived from the perennial weeds present on it and from the seeds present in the soil. Probably the grasses would consist principally of couch, soft brome and creeping bent. The next contribution to the flora is provided by wind-borne seeds, amongst which the minute seeds of various grasses are present in abundance. These naturally sown seeds germinate in the half shade of the existing vegetation, and by quickly establishing themselves tend to crowd out the annual weeds. If subsequent development is controlled by mowing or grazing, or by the use of fertilisers, a turf will result. Such turf can never be comparable in productivity with the well-established turf which results from sowing clean, well-tilled and well-fertilised land with an appropriate seeds mixture. Without a measure of control the self-sown pasture soon becomes colonised by brambles and thorn, thus preparing the way for scrub woodland and forest trees which is the ultimate natural flora of much of our agricultural land.

For generations the formation of permanent grassland from arable was recognised as one of the most difficult operations on the farm. Indeed it is safe to say that only since 1939, with the advent of improved mechanical equipment and the use of soil analysis on a wide scale, has the establishment of the grass sward become part of the normal routine of farm operations and rotations.

Land laid down to grass within the particular farm rotation prevailing is known as temporary ley. The length of time such leys are allowed to remain down before being ploughed out varies in different parts of the country and within the system of farming practised. They can, however, be put in two main groups, those of long duration (three years or more) and those of short duration (one to two years).

Long-duration Leys. Until comparatively recently the seeds mixtures sown for the purpose of establishing leys of a three-year duration or longer were made up of many different species of grasses and clovers which in total amounted to a seeding rate of some 40–50 lb. per acre. It was not uncommon for the mixtures used to contain as many as, or more than, twenty different species ; the assumption being made that sward formation would be assured by the establishment of some, at least, of these grasses and clovers. As the sward developed so some of the species present would grow when drought conditions occurred ; some would be better when conditions were more moist ; some would be early in spring growth while others would develop in midseason or in the autumn. Since the time that this type of seeds mixture was in vogue a great many grassland management studies have been carried out, together with the breeding of herbage plants suitable for particular growth environmental conditions. Furthermore, the factors influencing competition between species and varieties are better understood and as a result the tendency has been for seeds mixtures to become much less complex in their make-up and for far less seed per acre to be sown.

Long-duration leys can therefore be divided into two main types ; those in which the main grass will be perennial ryegrass and those in which the dominant grass will be meadow fescue. The former as a rule will be more widely used under the higher rainfall conditions of the west and north, while the latter are gaining ground in the east and south. Over the country as a whole on the lighter soils more liable to dry out, both perennial ryegrass- and meadow fescue-dominant mixtures include cocksfoot. This grows better under dry conditions than other grasses. Where the soils are a little heavier or of a more moist nature, some timothy rather than cocksfoot will be included in each case.

In addition to the grasses there is the possibility of including one of the varieties of red clover, usually late-flowering red clover, particularly if the ley is to be taken for hay or silage. Normally if the ley is to be grazed the red clovers will be omitted, and only white clovers put in to the mixture.

Long-duration leys often use lucerne as the main herbage plant, and in some instances grasses are included in these leys. Examples of these are given on page 290.

It is in the lower rainfall areas of the east and south that lucerne leys are mainly grown. Approximately half the total of 80,000 acres grown in Britain is to be found in East Anglia.

Typical examples of seeds mixtures that make use of bred varieties available on the commercial market, and of three to five years' duration are given below.

PERENNIAL RYEGRASS-DOMINANT, LONG-DURATION LEY

Perennial ryegrass S.24	8 lb. per acre
Perennial ryegrass S.23	4 ,, ,,
Cocksfoot S.37 *or* Timothy S.48	6 ,, ,,
Late-flowering red clover	2-3 ,, ,,
White clover, S.100 or Kersey	1½-2 ,, ,,

MEADOW FESCUE-DOMINANT, LONG-DURATION LEY

Meadow fescue S.215	10 lb. per acre
Meadow fescue S.53	2 ,, ,,
Timothy S.48	6 ,, ,,
Cocksfoot S.143	3 ,, ,,
Late-flowering red clover	2-3 ,, ,,
White clover S.100, or Kersey	1½-2 ,, ,,

The varieties that may be used in the compounding of seeds mixtures, such as those given above, may be other than those bred by British plant breeders. It is important, however, that when compounding any mixture the main growth characteristics of the varieties used should be known.

In many cases simplification of seeds mixtures and the reduction in the amount of seed sown have gone even further than in the examples noted above, so that ultimately a seeds mixture may consist solely of one grass variety and one variety of white clover, with a total seed rate of around 10 lb. per acre. In this way it is possible to make up seeds mixtures of different varieties of the same species or of different species and to sow them on separate areas. The potential growth character peculiar to any variety or species can then be fully expressed to provide herbage for pasturage or conservation at a more or less specified time during the growing season under the soil and climatic conditions prevailing.

These are called *ultra-simple* mixtures: examples which have given good results are:

(*a*)	Perennial ryegrass S.23	6 lb. per acre
	White clover S.100 or similar type . . .	4 ,, ,,
(*b*)	Cocksfoot S.143	6 ,, ,,
	White clover S.100, or similar type . . .	4 ,, ,,

The ultra-simple seeds mixture, although successful in the hands of a farmer familiar with sowing and managing such mixtures, can be disappointing where attention cannot be paid to details. In the latter circumstance the general type of seeds mixture usually gives more satisfactory results. With the ultra-simple seeds mixture it is essential to use a high tillering variety of the grass selected. Light as these seedlings appear to be they have given good ground cover. It is important, however, to ensure maximum plant establishment by sowing them only on land adequately supplied with lime and phosphate. When sown under a cereal nurse crop they should be sown immediately after the corn crop, thus minimising the amount of competition between the two for light, air, moisture and plant food.

Short-duration Leys. Whilst there is a measure of uniformity in the seeds mixtures prescribed for long-duration leys—and in practice there is virtually no difference between a mixture for a three- to five-year ley and one used for sowing down to permanent grass—for leys of shorter duration there is little uniformity. Probably because the purpose of these short leys varies so greatly in different districts, and even between one farm and the next, standardisation of seeds mixtures is impracticable. In the case of the one-year ley the purpose varies from the primary one of replenishing soil fertility under a four- or five-course system of farming to that of providing the maximum amount of fodder or grazing. For instance, the requirement may be for a heavy cut of hay ; or two crops of hay ; or a cut of hay plus aftermath for ploughing in or taking a seed crop, or simply abundant pasturage for sheep or cattle. In the case of the two-year ley the requirement may be for hay in each year ; for hay in the first year and grazing in the second year or vice versa ; or for grazing in both years. In most cases the two-year ley will be a compromise between the one-year ley and the three-year ley.

In general, for one-year leys, seeds mixtures designed primarily for hay will contain early-flowering or Broad red clover only ; or a mixture of grasses, principally Italian ryegrass and/or perennial ryegrass with a few pounds of Broad red clover. The latter type of mixture may also be grazed, in which case some large-leaved white clover and trefoil may be added, or trefoil alone may be used for stubble grazing. Where soil conditions are moist, alsike may be included and where clover rot is likely to attack Broad red clover, alsike may be used as a substitute.

For two-year leys either cocksfoot, timothy or meadow fescue may be introduced instead of, or as well as, the two ryegrasses, in which case the early varieties should be used. In addition ½–1 lb. per acre of a large-leaved white clover, such as S.100 or Kersey, will be included to give both high quality fodder and a mass of clover roots to plough down at the end of the second year.

Below are a number of examples of seeds mixtures for one- and two-year leys. These may be modified to suit specific requirements and particular conditions of soil and climate.

SEEDS MIXTURES FOR ONE - TWO YEAR LEYS IN LB. PER ACRE

	One-year leys			Two-year leys	
Italian ryegrass S.22	6	6	6	3	
Perennial ryegrass S.24		4	4	8	
Cocksfoot S.37				8	
Timothy S.51					6
Meadow fescue S.215					8
Alsike		3			
Trefoil			2		
Broad red clover	14	8	4	2	
Late-flowering red clover		4		2	6
White clover S.100, or Kersey			1	1	

A short-duration ley suitable for the purpose of providing " early bite " in the spring for dairy cows or ewes and lambs is one based solely on Italian ryegrass of a leafy persistent variety such as Aberystwyth S.22. This is seeded at 20–25 lb. per acre when undersown in cereal or at 30–35 lb. per acre when seeded direct in the spring or early autumn. When ready it is grazed intensively for 12–18 months before being ploughed out.

SOWING SEEDS MIXTURES

The sowing of seeds mixtures used in the formation of temporary or permanent grassland requires more care and attention to details than the sowing of the seed of any other farm crop. Conditions of soil and weather which would result in a satisfactory plant of wheat or swedes may often prove unsuitable for the establishment of grasses and clovers. In addition, because the seeds of these herbage plants are so very small, adverse factors such as a shortage of available plant food are likely to have much more serious consequences than in the case of the stronger seedlings arising from large, well-nourished seeds.

To ensure a successful " take " it is necessary to provide a clean, well-worked, compact seed-bed with a surface of 2–3 in. of finely crumbled soil. This can be most easily obtained after a root crop or fallow. If the sowing has to follow a cereal crop the recently shed seeds of annual weeds should, as far as possible, be forced to germinate by stirring the surface soil well before ploughing. Then, in the spring, the weathered furrow slices should be worked down to secure a fine, deep tilth. During the latter stages of the process a dressing of fertiliser supplying 50–70 units of phosphoric acid, 60 units of potash and 30 units of nitrogen should be given. When the seeds are undersown these fertilisers may be combine drilled along with the cereal nurse crop, in which case it may be expedient to use a phosphate/potash compound fertiliser for combine drilling and to apply the nitrogenous fertiliser as a top dressing. In this way the latter will benefit the cereal crop as well as assist in the early establishment stages of the grass and clover seeds mixture.

As soon as the surface soil is in a fit condition the seed should be sown broadcast by hand, fiddle drill, or seeds barrow, or drilled with a suitable coulter drill. In districts of average to high rainfall, broadcasting on the surface gives good results even on dry soils, but in the low rainfall areas it is necessary to place the seed in contact with the sub-surface moisture : this means using a coulter or disc drill and may involve placing the seed as deep as 1½–2 in. below the surface, although shallower drilling is desirable. Some drills sow at 3½–4 in. spacing, but if a corn drill spacing of 7 in. is used, to secure uniform distribution and to avoid undue competition between the germinating grasses and clovers in the drill, half the quantity of seed may be sown in one direction and the rest at right angles to it.

The Nurse Crop. Temporary leys are sown for the most part using a cereal as the " nurse " crop. With a spring variety of wheat, barley or oats the cereal is drilled as soon as conditions are favourable in March or early April. This crop is harrowed in and the land rolled before the grass and clover seeds mixture is sown ; it is advisable that the sowing of the small seeds should take place immediately following that of the cereal ; the small seeds in turn are harrowed in and rolled. In some cases the cereal may be brairded before the seeds mixture is sown, but in these circumstances there is always a risk that the cereal, already growing vigorously, will smother out the small, tender grass and clover seedlings.

When autumn-sown wheat or oats is the nurse crop there is usually a strong leafage by the time the seeds mixture is to be sown. To ensure that the small seeds will get a fair chance of establishment it is a good practice to remove the " flag " of the cereal by grazing it off with sheep or cattle, or even by mowing it. Provided this is carried out in most seasons before the end of April, the cereal does not suffer unduly and the grazing can be a useful additional feed at a time of year when a fresh succulent feed is very scarce. The practice has the additional advantage of counteracting lodging of the cereal. To obviate as far as possible the danger of lodging and the smothering of the seeds mixture, it is important to drill the cereal at an under-average seed rate and to select a short, stiff-strawed variety.

Seeding Direct. When long leys are sown or it is intended to sow a field to permanent grass, the nurse crop is often dispensed with and the seeds mixture sown on bare ground from March to May, or July to August—these being in most districts the " safe " periods for sowing. In such conditions it is not uncommon to include in the seeds mixture about 3–4 lb. per acre of Italian ryegrass or 2 lb. per acre of rape which, germinating rapidly, provide grazing for sheep or cattle, the treading of the stock being beneficial in the establishment of the sward. It is important to ensure that neither the Italian ryegrass nor the rape is allowed to get out of hand as this will lead to suppression of the more permanent constituents of the seeds mixture.

Weed Control. It is also important, whether the leys are undersown or direct seeded, that measures be taken to control the growth of broad-leaved weeds that may appear during the early stages of establishment. As with cereals and other arable crops, the means of weed control during the early phases of ley establishment have progressed considerably in recent years. Selective herbicides have been developed which will control many broad-leaved weeds when applied at the correct stage of cereal development, when the seeds mixture is undersown, and when the grass and clover seedlings are at a particular developmental phase when the seeds are undersown or direct sown. The selective herbicides used in this context are of the growth regulator type MCPB and 2,4-DB, or contact herbicides such as dinoseb. The value of these lies in the fact that they may be used without harm to the clovers in the seeds mixture (see Appendix VI).

Grazing. If the season has been favourable a considerable amount of herbage will be produced in the autumn by the time the cereal crop has been harvested. Stock can then be turned in to graze it lightly if the soil is not so wet as to be injured by treading. When sowing is done without a nurse crop, grazing will be possible from five to ten weeks after sowing the seed, depending upon weather conditions. The choice of stock for this grazing will be determined largely by the class of farm and the stock available ; some prefer sheep, others cattle. Cattle will graze the upright shoots of the grasses, whereas sheep prefer the side shoots : hence there is a danger that the sheep may graze too hard and injure the vitality of the plant. On the other hand, they tread more lightly. Perhaps the safest compromise is to select young cattle, but in any case care must be taken to avoid drastic grazing in the early stages whilst the sward is becoming established, and before a good sole or bottom has formed which is capable of carrying the stock.

In the case of a direct seeding without a nurse crop the establishment of the young seedlings can be assured by irrigation should facilities in terms of water and equipment be available for this purpose. This is particularly so if drought conditions are experienced shortly after seeding.

To Hay or Graze. In the following season the decision must be made between taking a crop of hay or continuing to graze. This decision does not apply, of course, in the case of one-year hay or grazing leys where the purpose is clear. Here again diverse views are held, some averring that grazing for the first two years when establishing a sward is important, others contending that the best procedure is to take a hay crop. In the latter case it is essential to cut the crop early, when the grasses first come into flower, and graze the aftermath : with this management little difference in results between mowing and grazing is likely to be noticed. On the other hand, to leave the hay crop until late in the season to gain the maximum weight per acre is harmful to the future of the sward.

THE MANURING, MANAGEMENT AND UTILISATION OF GRASSLAND

Soil conditions, climatic conditions and the constituents of the seeds mixtures sown all play a part in the production and development of grassland. The degree to which such grassland is capable of further herbage production and its conversion into saleable animal products largely rests with the standard of subsequent manuring and with the general management of the sward and method of utilisation. The quantity and quality of herbage growth, whether converted into animal products by way of pasturing or by conservation practices, hay, silage and dried grass, will largely depend on the availability of plant nutrients, particularly nitrogen, phosphate, potash and lime. These must be present in adequate quantities and at the correct time in relation to plant requirements. It is necessary, therefore, to have some understanding of the role that these play in maintaining and increasing grassland output and of how they may be used to advantage. To this end attention must be given to the condition of the grassland receiving the fertilisers to ensure favourable conditions for growth by mechanical treatment and proper drainage, and to the conversion of the herbage produced to animal products by the grazing animal directly or indirectly through methods of herbage conservation.

Manuring of Grassland. Since 1856 the effect of different fertilisers on permanent grassland has been under investigation at Rothamsted, the grassland in this case being used for the production of hay which enables yield data to be recorded. During this time also large numbers of manurial trials on both meadows and pastures have been carried out all over the country. It is on the results of these experiments that the manuring of grassland is now based.

Nitrogen. The first effect of applying to grassland any dressing capable of acting as a plant food material is to upset the equilibrium arrived at between the species composing its flora. Even if the rate of growth only is affected, some species grow more vigorously than others, with the result that they tend to crowd out others from the beginning. Under a system of grazing this is counteracted, and in the case of meadows may be controlled by grazing in some years instead of leaving the herbage to grow to its maximum length for hay production. By the judicious blending of fertilisers allied to wise grazing management it is possible to maintain a well-balanced sward at a high level of productivity for a long period of years.

The initial result of applying nitrogenous fertilisers to grassland is a great increase in the growth of the plants. The new growth is characteristically dark green in colour and distinctly more succulent than that of plants grown without an additional supply of nitrogen. All the nitrogenous fertilisers have this stimulating action, and their value for increasing the yield of hay or producing an early bite in the spring is well known. The application of 20 units of nitrogen per acre may be confidently expected to result in an increased yield of from 6 to 10 cwt. per acre of green herbage if the weather conditions are favourable. When the nitrogenous fertiliser is applied in mid-February to sheltered, well-drained fields, about a fortnight's earlier growth is obtained compared with fields not so treated. The value of this practice in connection with Italian ryegrass has already been noted and this is a system which is used more extensively as time goes on. Fields used for this purpose are top dressed with 40–60 units of nitrogen per acre in the late winter. Fields put up for silage must also be top dressed with similar quantities of nitrogenous fertiliser to give both bulk and quality. Nitrogen also has an effect on the quality of the hay produced, for when applied from ten to fourteen days before the crop is cut for hay an appreciable portion of the inorganic nitrogen is taken up immediately and converted into organic nitrogen, with the result that the protein content of the hay is increased. Any nitrogen not taken up by the plant is utilised later for the production of aftermath. The continued use of nitrogenous fertilisers on pastures and hay fields will reduce the proportion of clover present, partly by the overshadowing of the clovers by the increased growth of grass stimulated, and partly by the toxic effect of the nitrogen on the clover plant itself. To reduce this suppressive effect of nitrogen, adequate levels of phosphate and lime must be maintained.

Phosphate. Numerous trials with various phosphatic fertilisers have shown that, with comparatively rare exceptions, the result of their application is an abundant growth of all leguminous plants, and especially of white clover. Fields so treated, on which only traces of the plant can be found after careful searching, may become an almost continuous white clover mat after a single dressing. No complete explanation of this extraordinary development is available yet, but it is generally assumed that it is in some way connected with the bacteria-containing nodules which are so distinctive a feature of leguminous root systems. This stimulation of the clovers is of indirect benefit to the grasses, since the former accumulate nitrogenous materials which in time find their way into the soil and become available as food material for the grasses.

Potash. Lack of potash results in a decline in the yield of hay and silage, a retardation of the flowering period of the grasses and, in some cases, poor development of the clovers. Not all soils respond to potassic dressings and probably the potash requirements of grassland flora are amply met by the supply available in the soil, except in the case of those of an extremely sandy or gravelly nature, or where a soil analysis reveals a serious shortage of potash. With the increased use of nitrogenous fertilisers, particularly on temporary leys, attention must be given to additional potash requirement. Care, however, needs to be exercised in this respect as the excessive manuring of grassland with potash may lead to metabolic disturbance of the animals grazing thereon (see p. 710).

Lime. Although the grassland flora of soils overlying both chalk and limestone is usually rich in species the grasses, as a whole, are not calcareous plants, and most of those of agricultural value can thrive on soils with a low calcium content. Acid soils, however, are distinctly prejudicial to their growth, and very few species contrive to exist on really sour soils (see p. 31). Quite apart from the fact that the most productive herbage plants demand a non-acid soil, the maintenance of an adequate lime content in the soil ensures a high calcium content in the herbage, and this is acknowledged to be the best way in which to make sure that livestock have an ample supply of calcium in their diet. This is especially important for young growing animals, milking cows and all breeding stock.

Signs of lime deficiency in grassland are a preponderance of bent grasses, sheep's fescue and Yorkshire fog, together with tormentil (*Potentilla tormentilla*), heath bedstraw (*Galium saxatile*) and sour dock (*Rumex acetosa*). Under such conditions white clover will be present in traces only or it may be completely absent, and it is not uncommon for there to be considerable patches of bare earth. If the turf is lifted on these areas, the edges show sections of a skin of peat-like material consisting of the undecomposed remains of previous years' growth. This tends to increase in thickness year by year, for the processes of decay go on slowly under sour soil conditions. Rainwater falling on the surface is retained by the peat, with the result that after a dry season the soil below it may be dry for weeks after rain has fallen.

When heavily limed the peat mat gradually disintegrates, the process often going on so slowly that no effects are visible for some years. As it disappears the clovers re-establish themselves and the grazing improves considerably. But no pronounced changes occur in the flora, and the bent grasses still predominate. By tearing out the peaty material with heavily weighted spiked harrows prior to the application of lime, the decomposition of the mat is speeded up and the improvement greatly hastened. To be really effective, however, the harrowing should be drastic to the point of near destruction of the original sward. Phosphates, lime and some nitrogenous fertiliser are applied together with a simple grass seed mixture. In this way it is possible in time radically to improve the herbage, although the tough weed species will still persist and may ultimately regain dominance in the sward unless care is taken to nurture the sown species. This process is a form of pasture renovation discussed in more detail later, and is a method of reclamation advocated by some for certain conditions of terrain and soil type in place of the more drastic treatment necessitated by ploughing and reseeding.

To secure the best results from temporary leys, of long or short duration, it is essential to keep up the fertility of the soil. With long leys or permanent grassland the swards deteriorate as time goes on owing to the removal of food materials from the soil, either in the form of hay and silage or in the carcases of livestock or in milk. This deterioration is characterised by a markedly increased weediness in the grass flora. The judicious use of fertilisers in association with farmyard manure and lime will do much to prevent this deterioration. So great, however, are the differences in grassland floras, in soils and climates, as well as in the requirements of individual farmers, that it is impossible to do more than give general indications on the best fertiliser treatment.

Manuring for Hay and Silage. On dairy farms where the whole supply of farmyard manure is not required for the arable land, the yield of grassland for hay or silage may be maintained by the application of farmyard manure at a rate varying from 10–20 tons per acre. The disposal of dung and urine and cowshed washings by collection in a suitable tank container and its application in a diluted form to grassland being conserved as hay or silage is being practised on more holdings as time goes on. In Switzerland this practice has been carried out for many years and is known as the " Gülle " system. Where this practice is continued year by year the tendency is towards the production of a bulky and coarse herbage which is often rich in Yorkshire fog and weeds like dandelion, and singularly deficient in the better grasses and clovers.

Where farmyard manure is not available nitrogenous fertilisers are essential for the continuous production of herbage for hay and silage. Nitrogenous fertilisers for this purpose are applied in March or early April at the rate of 40–60 units of nitrogen per acre with the expectation, if weather conditions are favourable, of a yield of some 2 tons per acre of hay or 5–6 tons per acre of silage.

The use of farmyard manure and nitrogenous fertilisers alone is inadvisable as deterioration of the herbage is then inevitable : they should be supplemented at intervals with phosphatic fertilisers and lime. On light land an occasional application of a potassic fertiliser may also be called for.

A definite manurial rotation such as farmyard manure in the first year, phosphatic and nitrogenous fertilisers in the second, and nitrogenous fertilisers alone in the third and fourth year will do much towards keeping up the quality of the herbage as well as producing heavy crops for conservation. Fertiliser applications of this type may also be given as compound fertilisers containing the required nitrogen, phosphate and potash in suitable combination (see p. 183). An application of lime at intervals of four to seven years, depending upon the type of soil and the climate, will of course be necessary in most cases.

Manuring for Pasture. Leaving aside the value of an application of at least some nitrogenous fertiliser to grassland used as pasture, fertiliser requirements under these conditions will be mainly phosphates, particularly on the heavy and medium classes of soil, and of potash on the lighter sandy soils. Phosphates on permanent pasture may be applied in the form of basic slag, those containing a high content of phosphate being the most efficient. Increasing use is being made on temporary leys of the more soluble forms of phosphate, both superphosphate and triple superphosphate. Phosphate in compound form combined with nitrogen or potash may also be applied.

Recent work has shown that annual dressings of small amounts of phosphatic fertilisers to pastures give better returns in terms of herbage yield and quality than do heavier dressings at less frequent intervals.

Pastures on many different soil types benefit from liming ; even those situated on chalk formations may need to be dressed with lime. Pastures which demand heavy and frequent applications are those situated on the Millstone Grit and Coal Measures soil formations, especially when these are situated in industrial areas where the acid fumes aggravate the natural lime deficiency of the soil. Dressings are now usually made as ground limestone which is easy to store and handle. Under average conditions an application of 30 cwt. per acre of ground limestone every four years should be adequate to meet the needs of the pastures and the grazing stock.

Where the system of pasturage practised is extremely intensive, as is the case on some dairy farms in Britain, the application of nitrogenous fertilisers in quantity is necessary. This usually takes the form of an application of some 40–60 units of nitrogen per acre in late February or early March to provide early bite when the cows are first turned out to grass in the spring on to such grazings as Italian ryegrass. This may be followed by a similar further top dressing of 40–60 units of nitrogen per acre in April to stimulate herbage growth for a second grazing, or for conservation as silage, or in preparation for taking a seed crop. Where it is possible to irrigate, this dressing can be repeated in June but, unless water is available for irrigation, mid-season dressings of nitrogenous fertiliser may be largely ineffective in giving growth response.

Pastures of a more permanent nature than those used for early bite are given a dressing of about 40 units of nitrogen per acre in March or early April. This stimulates early growth, after which greater reliance is placed on maintaining the white clover in the sward to provide the nitrogen needed by the grass. Excess application of nitrogenous fertilisers to long-duration leys or permanent pastures will result in the suppression of the clovers.

Nitrogenous fertilisers may also be applied to stimulate autumn growth of pastures and so prolong the grazing season at that time of year. This autumn growth is being increasingly used to provide field grazing up to Christmas and the New Year.

Obviously, under an intensive system of grazing involving the use of heavy applications of nitrogenous fertiliser, it is vital to see that the soil is not depleted of the essential phosphate, potash and lime necessary to maintain an adequate and balanced supply of those plant nutrients. It is also important to ensure that the grazing stock are provided with mineral supplements when pastured in this manner.

THE CONTROL OF GRAZING

The intensification of pasture production by the breeding of improved varieties of grasses and clovers and the application of suitable fertilisers will lead to increased financial outlay. To recoup this it will be necessary to convert such increased production of herbage into an increase of saleable animal commodities. As little as possible of the herbage grown should be wasted and its utilisation by grazing livestock will need to be controlled. This is particularly so at certain times of the year when growth is rapid or when growth already made has to be rationed.

Utilisation by Cattle.

Soilage or " Zero Grazing ". This practice, which in essence is that of cutting green fodder and feeding it to stock confined permanently in yards or other suitable feeding area, has recently been revived in this country. This is largely due to the availability of forage harvesters capable of cutting and collecting green fodder, including grassland herbage, quickly and efficiently. In this way the main drawback of the system previously, the heavy demand on labour for cutting, collection and carting, has been eliminated.

The system offers considerable scope for maximum utilisation of any feed grown, and by its adoption cattle can be kept off the land so that the minimum of wastage due to soiling through stock excreta and treading takes place, although some damage may be caused by the cutting machinery. Fields at a distance from the homestead or milking unit, or badly placed for watering and fencing, can be laid down to temporary leys as part of the arable rotation, thus providing feed for the cattle from fields that are otherwise inaccessible to the grazing stock, while at the same time contributing towards the maintenance of soil fertility. Elaborate equipment for cutting and feeding is not necessary, and the use of self-feeding trailers for field collection and for feeding is a method of dispensing with the need for trough space and unloading of the trailers. The advantages of the system, however, have to be weighed against the fact that increased costs are involved in the daily cutting and carting of the fodder, as compared with allowing the stock to do their own harvesting by grazing.

Close Folding by Electric Fence. Apart from the particular circumstances prevailing when soilage is adopted as a method of utilisation control, field grazing will be the normal practice in this country. Intensive grassland husbandry for dairying or feeding for beef depends on the control of the grazing, partly to avoid wastage by treading and partly to ensure a high quality of feed over an extended period. This may be the case when grazing an early bite of Italian ryegrass in the spring or the feeding of " winter grass " on pastures laid up from the previous late summer or early autumn. The easiest system of control for this purpose is by close folding with the electric fence. This may entail one or two daily moves of a forward fence to allow sufficient feed to satisfy grazing requirements, and the bringing up of a back fence to prevent the continual grazing of the pasture already fed to the cattle.

Paddock Grazing. The basis of grazing control by paddock grazing is again to provide a high quality feed at a stage of growth to give the greatest return as animal products. The size of the paddocks is such as to provide grazing for the head of cattle carried for three to four days at a time. Alternatively the paddocks may be only of a size to provide the herd with one day's grazing, as in the case of close-folding with the electric fence. The fencing used can be of a temporary nature such as electric fencing, or of a more permanent type using post and wire. Ease of access to each paddock is essential. The rotation of grazing between a predetermined number of paddocks should allow a sufficient rest period for recovery of growth of young leafy herbage to take place by the next grazing. Any paddocks that grow beyond the grazing stage are omitted from the grazing rotation and cut for conservation.

Field Grazing. The extension of the paddock method of grazing control is field-by-field grazing. Here the cattle will be kept longer on a particular area, in all probability for more than ten days at a time. Attention should be given to the type of grass/clover mixture sown to ensure that the field comes for grazing at more or less specified times during the season. Field grazing can result in as high an output of cattle products as some of the methods of closer control, but the tendency is for field grazing to be lax, resulting in undue wastage of the pasturage.

Utilisation by Sheep. In parts of the country where there are extensive areas of grass for sheep grazing, as in the north and west, control of the grazing is largely based on a low stocking density, coupled with a not too rapid growth of grass. Where a higher stocking rate is possible, more especially of ewes and lambs, greater attention must be given to the provision of suitable grazing with regard to quality and type of feed and with a view to minimising the danger from intestinal parasites. The degree to which such control need be exercised will depend largely on the intensity of stocking envisaged. The greater the number of ewes and lambs carried per unit of area the greater the need for care and control of the grazing available.

Paddock or Field Grazing. Under a rotational system of paddock or field grazing, the carrying capacity of the grass will be 3–4 ewes and their lambs per acre during the spring and summer. Stock density should be such that sufficient high quality, leafy pasturage is available for the ewes for the first six to eight weeks after lambing to stimulate a sufficient flow of milk for the lambs. As the lambs get older such pasturage will allow them to make rapid gain in weight. The system involves either a permanent pasture or a temporary ley of four to six years' duration. Pasture management should be such as to allow, from the commencement of lambing, pasturage which grows with the ewes and lambs as these are transferred to it from the lambing field.

It is extremely important that in the grazing of these fields a year of grazing should alternate with a year in which the herbage is cut and conserved, or failing this, grazed with cattle. The grazing should allow for the maximum exposure of the base of the sward to sun and air, while at the same time it should not be so hard as to force the sheep to graze the basal herbage, containing the greater danger from parasite harbouring. This method of grazing control, coupled with anthelminthic dosing of ewes and lambs, will help to minimise the danger of parasitic infection, which to some degree is unavoidable, particularly as this affects the lambs. Essentially the grazing control should ensure as far as is possible that during its early life the lamb should graze as clean a pasture as possible, uncontaminated for at least a twelvemonth by previous sheep stocking and under conditions in which the ewe has but a low burden of intestinal parasites.

Creep Grazing. Where the carrying capacity is to be even higher than that under paddock or field grazing, that is 6–8 ewes and their lambs per acre from late March to late July, and where the maximum output of lamb is required, then still stricter control of both pasture quality and grazing method will be necessary. This can be provided by *creep grazing* which, in essence, is arable sheep folding transferred to an intensive grass regime. For this method of intensive grazing the field should be completely free from parasitic infestation likely to affect sheep. To ensure this, a field that has not been grazed by sheep for at least a twelvemonth, or preferably a new ley, must be provided. Superimposed on this will need to be a system of fencing of a temporary type by means of which pasturage can be made available to the ewes for three to four days at a grazing. In addition, the fencing must allow the lambs to have access to pasture not grazed by the ewes. This will be possible by *forward creep grazing* of the lambs where eventually the pasture will also be grazed by the ewes ; or by *sideways creep*, where the pasturage provided for the lambs need not be grazed by the ewes later on and so contaminated.

By the adoption of a creep grazing system immediately following lambing, the ewes can be given high quality pasturage and the lambs will gain weight rapidly from the milk flow so stimulated. As the lambs grow older the milk flow of the ewes can be pulled down by the gradual reduction in the quantity and quality of the pasturage, while the lambs will continue to improve by the provision of a greater area of clean, high quality grass.

Irrigation of Grassland. In the eastern and southern parts of Britain it is considered that grassland irrigation will give increased yields of herbage four years out of five. The amount of this increase will vary from year to year giving a 50 per cent increase in an average rainfall summer to over 100 per cent increase in dry summers. Normal pasture yields in Britain from temporary leys average some 6,000 lb. per acre of dry matter. This may be increased to some 9,000–12,000 lb. per acre dry matter yield by a combination of irrigation and nitrogenous fertiliser application. From 200–300 lb. per acre increase of dry matter yield will be obtained per acre inch of water applied, and the best returns are to be had when the water deficit is not allowed to get beyond ½–1 in. The financial returns from grassland irrigation must be carefully estimated before embarking on such a scheme. It is important to keep the cost of the supply of water and its means so distribution as low as possible to make the enterprise a worthwhile proposition (see p. 211).

Winter Grazing. The improvement in the winter greenness quality of grass varieties and the availability of quick-acting nitrogenous fertilisers has led to an extension of the period of growth of pastures in the late summer and autumn. In some areas where conditions of soil and climate are favourable it has been found possible to extend this period up to Christmas and even into the New Year. For this purpose the growth of suitable grasses is stimulated by the application of about 60 units per acre of nitrogen in mid-August and this resultant growth grazed from late October onwards. Grasses that have given good results in this respect are cocksfoot and tall fescue, particularly when these are sown in drills 10–14 in. apart or in alternate drills with lucerne at the same spacing. The seeding rate of the grasses should be 5–6 lb. per acre and of the lucerne 4–6 lb. per acre. The grazing of the herbage grown in this way must be controlled by a rationing system. The subsequent summer production from these pastures is not reduced by the winter grazing. The sowing in drills prevents undue rotting of the herbage before it is grazed in the winter and the lucerne drills, consisting at this time of dormant plants, which are not harmed by the grazing, help to increase the amount of herbage produced in the following spring and summer.

DRAINAGE AND MECHANICAL TREATMENT OF GRASSLAND

Good drainage is a prerequisite of good grassland management. Soils that are badly drained restrict the rooting range of most herbage species. Where the water table is high it will result in the killing out of the deeper ranging roots so that if dry conditions occur later on, only the surface roots will be functioning and these will be unable to draw on the water reserves in the lower horizons and at the same time supply the minerals necessary for herbage growth.

Productive grassland should not be allowed to deteriorate into a matted condition. At least once in the season grasses and clovers benefit from a good harrowing with spiked harrows which cut into the turf and aerate the soil. Special turf-cutting blades can be fitted to spring tine harrows for this purpose, or one can purchase a special grass harrow of which there are many efficient types on the market. Combing to tear out dead grass can best be carried out during late autumn or winter. Before growth commences in the spring a light harrowing to spread mole-hills, droppings and the like is beneficial and, in most cases, grassland this time of the year benefits from a good rolling. This is especially useful on stony land which is to be mown over hay, since the stones are pressed into the soil out of the way of the knives of the mowing machine.

Intensive pasture utilisation often leads to unpalatable herbage developing in the vicinity of the dung and urine patches. The spreading of the dung pats is effected by winter and spring harrowing and the degree of unpalatability developing may be minimised by alternate grazing and cutting of the herbage either during the season or from year to year and by heavier top dressings of suitable fertilisers.

The mowing machine, of a reciprocating knife type or of the cylindrical or horizontal rotary knife type, should also be used as an aid to good pasture maintenance. Deterioration of a sward is rapid when persistent understocking allows the more vigorous grasses to become dominant and crowd out the finer grasses and clovers. To prevent this during periods of rapid growth the area allowed to the grazing animals should be restricted by using temporary fencing and cutting the surplus grass for hay or silage. An occasional " mow-over " is also useful to prevent tufts of grass from forming and to remove any seed heads which have formed, thereby encouraging the grasses to produce more leaf.

Weed Control. A good control of weeds in long-duration leys or permanent pastures can be effected by the use of the mowing machine. This control can be supplemented by the use of selective herbicides similar to those used in the control of broad-leaved weeds during the seedling phase of grassland establishment. Research work has shown that where weeds such as buttercups are eliminated from pastures heavily infested by these plants, increased production of herbage will only result following the application of suitable fertilisers in addition to the herbicide.

Pastures infested with Soft rush (*Juncus effusus*) can be improved by spraying the rushes with MCPA or 2,4-D. The spraying should take place before flowering when the rushes are growing vigorously and the rushes should then be cut some four weeks after treatment.

Gorse (*Ulex spp.*) in pastures may be cleared by the use of a 2,4,5-T spray and the underlying sward encouraged to improve by suitable renovation techniques.

GRASSLAND RENOVATION

The renovation of permanent grassland by mechanical treatment and the application of lime and fertilisers with the addition of a seeds mixture, has already been described briefly.

Sod-Seeding. Interest is being shown in what are described as the "sod-seeding" methods of improvement ; in some instances where these methods are applicable the grassland may be fairly open and renovating seeds can be drilled in to supplement the existing herbage ; in other situations the grasslands consist of a close turf and before seeds are drilled-in a wedge of soil is removed by the coulter of a drill adapted for this purpose ; the seed and fertiliser are then sown into the ground exposed by the removal of the wedge. The drilling of seeds direct into a close turf would result in little improvement of the sward as the sown seeds have little chance of survival in competition with the already existing grasses. In many cases the improvements brought about by these treatments may be both slight in amount and slow in development : in some cases there may be no improvement and little return for the money and time expended.

Ploughing and Reseeding. Better and quicker returns can in many situations be obtained by ploughing and direct reseeding. Direct reseeding involves ploughing the old turf completely under and bringing to the surface sufficient soil to form a seed-bed. This is then treated with the appropriate amount of lime and phosphates (determined by soil analysis), these being worked into the surface soil during the seed-bed preparing operations, which are carried out in most cases by means of disc harrows. Potash fertilisers may be applied if necessary, and prior to sowing the seeds mixture 20–40 units of nitrogen per acre should be applied to encourage rapid growth of the young seedlings. With favourable growing weather these come away rapidly and grazing is likely to be possible about two months after seeding. Careful costings have indicated that in most cases direct reseeding in this way is in the long run cheaper than renovation, although the initial cost may be considerably higher.

The Pioneer Crop. Under conditions of extreme poverty the sowing of a good seeds mixture in the first instance is seldom justified and, following ploughing and the application of the appropriate fertilisers, it is frequently advisable in such conditions to sow what is termed a *pioneer mixture*. A common mixture of this type is :

Italian ryegrass	16 lb. per acre
Rape	2 ,, ,,
Hardy green turnips	2 ,, ,,

This will provide abundant keep for sheep or cattle a few weeks after sowing. The crop is grazed down during the first year, and in the second a good disc harrowing may be given, after which the same seeds mixture can again be sown with the aid of 20 units of nitrogen per acre. This crop is again stocked heavily, and the dung and urine passed into the soil encourage rapid bacterial activity which brings about the decomposition of the mat. Lime and phosphates become intimately mixed with the soil, and after this pre-treatment, the land can once more be ploughed, thoroughly cultivated, refertilised and a good seeds mixture sown with every hope of securing a really productive and lasting turf.

Chemical Destruction of the Sward. With the discovery of grass-killing chemicals such as dalapon and aminotriazole, a method of pasture renovation has been developed whereby the sward is first destroyed by chemical spraying. The method is particularly useful where conditions of terrain are unsuitable for ploughing or where it may be difficult to reconsolidate the soil once consolidation has been broken up by ploughing. After the killing of the turf the land is rotary cultivated as shallow as possible to produce a surface tilth ; fertilisers are applied, the seeds sown and the land harrowed and rolled. As with the ploughing method this type of renovation may be carried out in steps ; first by improving the condition of the soil with pioneer cropping and following this with the permanent seeds mixture when these initial improvements have taken place.

GRASSLAND POTENTIAL

In recent years the aim in grassland management has been to increase the production from grassland by growing greater quantities of herbage, by more intensive utilisation of this herbage and by better and cheaper methods of conversion into the main products resulting from grazing stock. By paying attention to the environmental conditions under which grassland herbage is grown, by improving the varieties and seeds mixtures in use, by adequate fertiliser application and by weed control, much improvement has been effected. Management practices with regard to " early bite ", summer production and the extension of grazing into the autumn and winter have played their part coupled with grassland conservation as good quality hay and silage. The development of other techniques where these are suitable, for instance irrigation, zero grazing and pasture renovation, helps to increase the potentiality of our grasslands in the feeding of the appropriate livestock over a greater part of the year. This in itself can also lead to a reduction in the amount of supplementary feed required from other sources. In a pastoral country, such as Britain, there is need for expansion along these lines and every endeavour should be made towards the adequate feeding of our livestock from all sources of home feed production.

GROWING GRASSES AND CLOVERS FOR SEED

In Britain up to the outbreak of the second world war the cultivation of grasses for their seed was a local occupation carried out in parts of Northern Ireland, Scotland, Kent and East Anglia. This was also the position with the growing of clovers for seed, and certain local varieties were well known by their district of origin. Examples were to be found in Essex, Suffolk, the Cotswolds, Hampshire and Montgomeryshire. As a result of the breeding of new varieties, particularly those from the Welsh Plant Breeding Station, the need arose for these varieties to be multiplied and supplied to the seed trade under conditions that would ensure complete authenticity of the varieties grown.

In consequence an organisation, under the direction of the National Institute of Agricultural Botany, Cambridge, known as the National Scheme for the Comprehensive Certification of Herbage Seeds, was set up. This scheme controls the production of all bred varieties from officially sponsored sources in Britain through the various stages of seed multiplication necessary between the breeder and the retailer. The scheme also encourages the production of authentic seed supplies of varieties of local origin, and arranges for the growing of varieties bred abroad to be multiplied for seed purposes under controlled conditions in this country. Some 40,000 acres of herbage seed of Aberystwyth varieties are at present (1961) grown in Britain.

Most herbage seed crops are perennial, with the exception of such species as Italian ryegrass and Broad red clover which are virtually biennial. On arable farms the grass or clover seed crop takes the place, in the rotation, of leys of three to four years' duration. A well-managed herbage seed crop has the advantage of a cash crop of high potential financial return while at the same time providing a break in the sequence of arable cropping as well as improving soil condition.

On mixed, or predominantly grassland farms, herbage seed crops combine the function of providing some grazing for the stock with that of a cash crop, providing low quality hay as a by-product.

The main herbage seed producing areas in Britain are to be found in the east and south, where a relatively low rainfall allows harvesting to be carried out with reasonable chances of success. Other areas, for example parts of Northern Ireland and Scotland, also contribute to this section of the agricultural industry.

GRASS SEED PRODUCTION

The chief grasses grown for seed in Britain are perennial ryegrass, Italian ryegrass, cocksfoot, timothy, meadow fescue, tall fescue and red fescue. In choosing a field for the growing of a seed crop of any species of grass, and in particular of any of the bred varieties such as those from Aberystwyth, it is essential that the land be free from seeds of that species, and that the isolation of the crop shall be such as to prevent cross-fertilisation from neighbouring crops.

Clean Land. With regard to clean land it is obviously desirable to avoid complications from the usual annual and perennial weeds, some of which have seeds that are difficult to clean out of the seeds of the crop. For example, it is not easy to separate completely the seeds of the ryegrasses from cocksfoot, or of blackgrass (*Alopecurus myosuroides*) from the ryegrasses or from cocksfoot or meadow fescue. If a variety of any grass species is to be grown for seed it is necessary to make as certain as possible that seeds of any other variety of that species are not present in the soil, for they would germinate, grow and form seed along with the crop. To prevent this when growing grass seed under the Comprehensive Scheme an interval of four years' satisfactory cropping must have taken place before sowing the seed crop. A longer period is necessary when it is intended to grow certain local varieties for seed. In a similar way contamination from stray seeds may arise through the feeding of hay upon leys on arable land.

Isolation. Since grasses are wind pollinated it is desirable that a seed crop should be as far away from potential sources of contamination—such as a hay crop—as possible. Usually a distance of not less than 200 yd. from a possible source of contamination is insisted upon. A closely grazed pasture is not regarded as a likely source, and it is sometimes possible to satisfy isolation requirements by mowing-over at the correct time a field of grass and clover seeds situated less than the required distance from the seed crop.

It is not sufficient that the field be clean and well isolated. It must also be in good heart, for the production of satisfactory seed crops depends very much upon a fertile condition of the soil. Yields of seed are greatly increased by judicious manuring, but it is possible also to over-manure and give rise to a laid and tangled condition which greatly hinders harvesting.

Drilling Seed. Cocksfoot, timothy, tall fescue and red fescue are usually grown in drills 18–24 in. apart, although both cocksfoot and timothy are sometimes sown broadcast. Perennial ryegrass, Italian ryegrass and meadow fescue are, however, grown as broadcast stands or in narrow drills up to 14 in. apart.

The wide-drill crops are best sown without a cover crop, while those sown broadcast suffer less when undersown. Should it be necessary to undersow the wide drill crops, care should be taken to avoid undue suppression by the cover crop by reducing its seeding rate or by blocking a coulter from sowing the cover crop and planting the grass seed in this vacant drill. Large seeded grasses such as the ryegrasses or cocksfoot may be sown from ¾–1½ in. deep, but timothy with a small seed should be sown as shallow as possible, normally not more than ½ in. deep. Seeding rates should be as low as possible consistent with satisfactory establishment. For large seeded grasses in drills 4–6 lb. per acre is ample, and 10–15 lb. per acre when sown broadcast. The smaller seeded grasses are usually sown at 2–4 lb. per acre in drills and 6–8 lb. per acre broadcast.

Weed Control. Undue competition from weeds during the early stages of establishment must be avoided. As most grass seed crops do not have a companion clover a greater choice is possible in the use of selective herbicides for this purpose, without danger of damaging the grass seedlings. When the grasses are beginning to tiller, MCPA, 2,4-D, CMPP and dinoseb will give satisfactory results with the particular weeds which each of these effectively controls (see Appendix VI). Where clovers are present with the grasses only MCPB and 2,4-DB can be used for spraying. In the year when the grass seed crop is being put up for seed these chemicals can again be used to control broad-leaved weeds in the crop. Care must be taken not to spray earlier than four to five weeks before ear emergence is expected or later than the time of ear emergence.

Management. Cereal cover crops should be removed as soon as possible and the stooks or straw must not be left on the field longer than is absolutely necessary. Vigorous crops of ryegrass may be grazed lightly some six to eight weeks after planting if not undersown, but this grazing should not be prolonged and the crops should be allowed to recover before winter. Other grass seed crops are not normally grazed in the seeding year unless excessive leaf growth is present and there is a likelihood of frost damage if this is carried into the winter. In this case a light grazing to remove the excess leaf is advisable.

Direct sown crops are normally given a complete fertiliser dressing at seeding time, and these should not require more fertiliser before the following spring unless they show lack of growth. In the event of this a top dressing of 20–30 units of nitrogen per acre should be given in the autumn. Undersown crops should be given a complete fertiliser dressing at this time of 20–40 units of nitrogen, 40 units of phosphoric acid, and 30–60 units of potash.

In the spring of the first harvest year most crops will need a top dressing of nitrogen in late February or early March. The quantity given will vary according to the grass seed crop, but usually ranges in amount from 40–80 units of nitrogen per acre in the case of meadow fescue to 120–160 units per acre for cocksfoot.

Harvesting. Grass seed crops may be harvested in a number of different ways ; by cutting with a binder, stooking and then threshing from the stook or from the stack using the combine harvester as a threshing drum ; by cutting with a mower into swathe and threshing from the swathe using a combine harvester with a suitable pick-up attachment ; or by combining direct. Threshing out of the swathe with the combine harvester or direct combining usually necessitates artificial drying of the seed under carefully controlled temperatures.

After harvest the grass crop stubble should be cleaned up by grazing or burning or topping over with a mower and further fertiliser top dressing given. For most crops this will entail a dressing, per acre, of 60 units of nitrogen, 50–60 units of phosphoric acid and 60–120 units of potash. After autumn resting the stand may be grazed during the winter ; the time and duration of the grazing will vary with the different grass crops. Cocksfoot, for example, may be grazed up to the end of January and timothy to the end of February without reduction in the yield of the following seed crop.

A spring dressing of nitrogen will again be given in the second harvest year similar to that of the first harvest year. Treatment in subsequent harvest years will then follow this same general pattern.

CLOVER SEED PRODUCTION

The two clovers most widely grown for seed in Britain are red clover and white clover ; some interest is still shown in sainfoin and more recently in lucerne. Except for certain areas which have specialised for some time in producing seed of well-known local varieties, the harvesting of red clover seed has been somewhat haphazard. In times of seed scarcity farmers frequently allow the aftermath of Broad red clover to mature and thresh out the seed which may be of very mixed origin. With the setting up of the Comprehensive Seed Certification Scheme more attention is being paid to the multiplication of stocks of red clover of known origin.

The choice of a field for clover seed production will be governed by the same general standards with regard to the cleanliness of the field, previous cropping and isolation as for the grass seed crops. Most soils are suitable except land likely to dry out badly in summer, and very fertile land where excessive leaf may be produced thus reducing the amount of flowering and making harvesting conditions difficult. Small fields are preferable to large ones as they are worked more thoroughly by the pollinating insects. This is particularly the case with late flowering red clover where the main pollinator is the humble bee.

Seeding. Red and white clovers are both normally sown under a cereal cover crop fairly early in the spring, by mid-April if possible in low rainfall areas or early May in the wetter districts. Preferably they should be sown immediately following the sowing of the cereal.

Seed rates of 6–8 lb. per acre of red clover and 2–4 lb. per acre of white clover are customary, with a sowing depth of not more than 1 in. and ½ in. respectively. White clover may be sown also with 3–6 lb. per acre of meadow fescue or of a pasture variety of perennial ryegrass, but seed yields are likely to be reduced.

Red and white clovers need adequate reserves of lime in the soil, while both benefit from reserves of phosphate and potash or from the application of these fertilisers prior to seeding : 50–60 units per acre of phosphoric acid and 60 units per acre of potash are the standard applications at this time.

At harvest the cover crop and its attendant straw should be removed as early as possible. A light grazing at this time may be beneficial, more especially if the growth of the clovers is forward and likely to go into the winter in too proud a condition. This grazing must, however, not be too severe.

The control of weeds in the seed-bed in the seeding year is important. For this purpose, provided the cereal has reached its resistant growth stage and the clovers are in their first trifoliate leaf, MCPB and 2,4-DB are satisfactory. In the year of putting up to seed, however, no safe herbicide is at present available for red clover although MCPB and 2,4-DB may be used for seed crops of white clover. With the latter the spray must be applied immediately previous to the crop being put up for seed in mid to late May. Crops that are allowed to grow through to seed harvest without grazing or cutting must not be sprayed in this way.

Under reasonable conditions of soil fertility, fertiliser application in the first harvest year will not be necessary.

Harvesting. The decision as to when a crop of clover should be closed up for seed is not easy to make, particularly when dealing with white clover. Broad red clover may be taken for silage or hay in late May or early June, while crops of late flowering red clover are best cut or grazed in early spring. This must be done not later than the end of May with the extra late varieties. White clover is generally closed up from the second to third week in May depending on the season, a dry season necessitating an earlier closing time.

Broad red clover is only taken for seed in the one year, while late flowering red clover varieties may be taken a second time although the yield is usually reduced in the second crop. White clover can be taken for two to three years.

Seed harvest of white clover is in late July and of red clover between late August and the end of September. In the past clover seed crops were cut and stacked and then threshed with a clover huller. Nowadays it is more usual to cut and swathe and to thresh out of the swathe using the combine harvester fitted with pick-up attachment. Red clover may be direct combined and to assist in this under moist weather conditions it is advisable to desiccate the clover leaf previous to harvesting. Suitable desiccants are DNOC or sulphuric acid, or a recently available product, diquat.

Chapter XII

THE CONSERVATION OF FODDER CROPS

In Britain, during winter, pasturage is scarce and of poor nutritive value. Therefore, in order adequately to feed cattle and to a less extent sheep, it is necessary to conserve for later use a proportion of what is grown in spring and summer. Fodder conservation is not considered to include the saving of roots, tubers or grains but only those crops which require processing in some way to prevent deterioration. The raw materials include a range of crops and by-products of crops, of which the grasses and clovers are the most important. All have one thing in common : they contain a high proportion of water at the stage of growth when they are suitable for preservation.

Faced with this situation, the farmer has two alternatives. He can either dry the crops to the stage at which bacterial and fungal decomposition ceases (about 15 per cent moisture) : or he can make them into silage, which is preserved by organic acids formed during the fermentation process. Almost all the fodder crops are suitable for silage, but some are less suitable for hay making or artificial drying, the two common methods of removal of water.

ARTIFICIAL DRYING

Artificial drying is usually known as " grass drying ", although a large proportion of the green fodder dealt with in this way is composed of pure lucerne. It differs fundamentally from hay and silage making, firstly in the relatively high expenditure on machinery and fuel, and secondly in the stage of crop growth at which it is conducted. Because of the expense of the process, crops must be young and nutritious so that the resultant product is a concentrated rather than a bulky food.

Suitable crops for grass drying are permanent pastures or leys in the wetter areas, and pure lucerne or lucerne/grass mixtures in the drier areas. These may be cut three or four times in a year at an early stage of growth and produce a total of 2–3 tons of dried grass per acre. The dried material may be baled or passed through a hammer mill, in which case it is stored in paper sacks.

A ton of young grass growing in a field may contain 3½ cwt. of dry matter and 16½ cwt. of water. During the drying process it is necessary to evaporate 16¼ cwt. of water to obtain 3¾ cwt. of dried grass of 6–7 per cent moisture content. With a coke-fired drier, 16¼ cwt. of water can be evaporated by burning about 2½ cwt. of coke. It is this high ratio between the quantity of fuel and the weight of the resultant product which makes it so important only to work on very nutritious crops, and to weigh the extra convenience of oil-firing as compared with coke-firing against the extra fuel cost (oil being the more expensive per thermal unit of energy).

The normal practice is to harvest the growing crop with a cutter/

loader ; the drier may be of the batch or endless-conveyor type. In either case air heated to about 300° F. is blown through the crop, and it passes first through grass that is nearly dry and secondly through grass that has only just begun to dry : this is in order to obtain a high drying efficiency. After drying, the crop is cooled before baling or milling.

Fuel cost per cwt. of dried grass can be reduced if the crop is cut and left in a swathe to wilt for 24 hours before being collected. Nevertheless, apart from periods of high cattle food prices, artificial drying cannot often be justified economically on the ordinary farm. It is the most efficient method of conservation available if a comparison is made between the total food value of the growing crop and the total food value of the conserved product : losses usually only amount to about 5 per cent. The carotene content of dried grass is also high, varying from 200-400 milligrams per Kilo. On average, dried grass contains 6-10 per cent of moisture, and from 10 to 20 per cent of crude protein.

HAY-MAKING

Crops grown for hay include grasses, legumes, and occasionally cereals. They may be used as pure species or more usually as mixed swards. Taking the country as a whole, most of the hay comes from permanent pastures and this is especially the case in pastoral areas, but in the drier arable districts one-year and other short-term leys are predominant. The clovers are the commonest legumes, with white clover contributing to long leys and permanent grass and red clover to the short leys ; but lucerne, sanfoin, vetches and peas are also used.

Quality in Hay. One of the most important principles in all fodder conservation work is this : *a nutritious fodder can only come from a nutritious crop at the date of harvest.* If the harvest is too late nothing done subsequently can retrieve a position already lost. As pasture plants mature so the protein content and, to a less extent, the ash content falls. At the same time, the fibre content rises steadily. Leaves have a higher protein and ash content than stems and a lower fibre content. Thus, if there is any choice in the matter, hay is better harvested from leafy, early cut swards than from stemmy, late cut, ones.

The percentage of protein is a useful index of herbage quality but not the only one : the digestibility of the crop is also important. It has been found that grasses and clovers vary between different species, but in general they remain highly digestible until a certain stage of growth and then lose digestibility at an increasing rate thereafter. In this way, although the total quantity of protein and carbohydrate may continue to increase, the quantity of digestible nutrients declines. The actual date at which this factor becomes a dominant consideration varies geographically and from crop to crop. With first cuts in the south of England it is usually in the latter half of May : further north it will be later. The growth stage at which it occurs is just before the emergence of the majority of the flowering heads (see also p. 301).

Although there are strong reasons for cutting hay at an early growth stage, before it has reached its maximum weight per acre, it is unfortunate that the most suitable weather is not normally in the early part of the summer. Hay making requires maximum use to be made of dry weather and, on average, the chances for field drying improve from the middle of May to the middle of July and deteriorate from the middle of August to the middle of October. It is for this reason that so much hay is made too late to give it a chance of being of good quality.

Another difficulty of early hay making, in addition to poor weather, is the fact that immature crops contain a higher proportion of water and dry less quickly than mature crops. On the other hand light crops dry more quickly than heavy crops.

Taking all the known principles together, their effects may be summarised by stating that although the risk is greater in making hay early from a young crop, the possible advantage of doing so is sufficient to make the risk worth taking, and additional skill in management can be used to redress the balance.

Methods of making Hay. In the description of methods below it is assumed that the crop dealt with is young and leafy. If it is old and stemmy the task is much easier and does not warrant detailed discussion.

The process involves nothing more than the evaporation of water to such a level that the material can be stored with safety. This simple statement is intended to dispel any impression that the operation involves any mysterious " curing " : hay making is often difficult but none the less simple in principle.

The crop is cut with a hay mower. Many farmers believe in starting this task after the morning dew has been dispelled, but there is experimental evidence that no practical advantage is gained from so doing. If fine weather is expected a start can be made as soon in the day as convenient.

Freshly-cut grass has two important characteristics. Firstly, it is supple and, therefore, can be shaken or tossed vigorously by machinery without suffering any damage, whereas nearly dry hay is easily fragmented by rough handling and leafy parts are lost in the stubble. Secondly, newly-mown hay is not susceptible to damage from rain because the still turgid cells and waxy epidermis make the plants waterproof, whereas partly dried hay is liable to lose a considerable proportion of the water-soluble nutrients by leaching. Consideration of the latter factor leads to the practical conclusion that there are occasions in showery weather when cut hay suffers less damage if drying has been delayed : but there are more often compelling reasons why the drying process should be hastened in order to limit the period during which the crop remains in the field.

An unbroken swath, as left by the mower, exposes only a small surface area to sun and wind : it dries slowly and unevenly. If, on the other hand, the swath is fluffed up, the evaporation of water is encouraged by free circulation of air through it. The sooner a tedding machine is used after mowing and the more often it is used thereafter, the more quickly the hay will dry, so long as the weather remains fine. At this stage the hay should be treated in swaths which cover the whole field, rather than in windrows which only cover a part and thus limit evaporation. Some of our leading farmers use a modification of this principle whenever possible. They " ted " the crop in the swath during the day, and then windrow it in the evening to reduce the area of hay upon which the dew can fall and in addition the ground between the windrows is allowed to dry before the hay is spread out again the next day.

Conditioning Machines. Speed of drying is the essence of making high-quality hay and there are various machines which may be used to accelerate the process. In the ordinary way plant stems dry more slowly than the leaves, but " conditioning " machines aim to flatten or kink the stems without breaking them, so that stems and leaves dry at the same speed.

The Flail Forage Harvester. Although not primarily designed for the purpose, a flail forage harvester can be used to this end, but it is necessary to exercise some forethought concerning what the effects may be. If a flail harvester is used as a cutting machine instead of the conventional mower and the crop is young, heavy, or leguminous, there is bound to be considerable fragmentation and loss of the leaves. But if the crop is light and fibrous the same operation is attended by little damage. Another and better possibility is to use a flail harvester as a tedding machine immediately after cutting : some flail harvesters may be fitted with special tedding tines and in this way the degree of laceration is reduced.

The Crimper. Of the special purpose machines the " crimper " may be taken as an example. It picks up and passes the crop between two interlocking fluted rollers which crush or crimp the stems at short intervals ; it leaves behind it a well-ventilated swath which dries very quickly. The crimper is used only once, i.e. immediately after cutting : a tedder and side rake are still required for subsequent operations.

Field studies have shown that if a heavy crop is treated with a crimper it is likely to reach 25 per cent moisture content (suitable for baling) about two days earlier than a similar crop which has only been tedded.

The fear has often been expressed that hay treated in the way described may be damaged more by rain than hay treated with a tedder. Experience has shown such fears to be exaggerated if not groundless. In one detailed study, when an inch of rain fell on partly-dried hay that had been tedded and partly dried hay that had been crimped, the weight per acre after collection of the latter was equal to the former and the nutritive value was equally high. It was also found that both before and after the wetting the crimped hay dried more quickly than the tedded.

A very large area of hay in total is made on very small holdings where the scythe and hand rake are more appropriate than an array of expensive machinery. The system is simple and laborious and not likely to be assisted by a discussion of fundamental principles. From these simple methods to the fully mechanised there are gradations in methods of collection too numerous to mention and only one traditional system will be dealt with briefly. On many farms, hay that has been partly dried in the swath is collected together and built into cocks or pikes in the field and it is left in this form to dry further before carting. It is usual for the cocks to be small in the drier parts of the country and large (containing about 15 cwt. each) in the wetter areas. In the drier areas the cocks are allowed to dry completely and they are then built into large stacks, or baled. In the wetter areas field drying does not proceed so far, and the cocks are made into small stacks in the rickyard in the expectation that further drying will take place afterwards.

The Pick-up Baler. On many farms where hay was formerly made into cocks and carted loose, use of the pick-up baler has gradually increased. The chief reason for this change is that the baler substantially reduces the amount of manual labour involved by older methods, in collecting, transporting, stacking, and finally cutting out and feeding hay stacked loose. The quantity of hay in bales can also be estimated accurately and rationed feeding is easier.

The pick-up baler has often been blamed for producing mouldy hay. Like many another useful machine it only gives good results when operated intelligently and in suitable conditions. It requires that the hay should be dry enough for baling and the bales should not be neglected thereafter. The decision when to bale is helped by knowing what will happen to hay at various stages of dryness if it is baled :

Hay containing 35 per cent moisture will rot.
,, ,, 30 ,, ,, ,, will mould and heat.
,, ,, 25 ,, ,, ,, may mould unless it is given the opportunity to dry out further.
,, ,, 20 ,, ,, ,, is safe to store in Dutch barns and thatched stacks.

From the information above it is seen that hay baled at 25 per cent moisture, as it often is in practice, must be left to dry further in the field or some special arrangements must be made for it indoors, whereas hay a little drier may be baled, carted, and stacked, immediately. The indoor conditions in which further drying is possible include good ventilation and stacking with numerous air spaces between the bales. After a short period the bales can be moved and stacked more closely, thus reducing the space required.

If the baler invariably picked up and collected the whole of the crop lying in the field, it would nearly always be better to dry to a low moisture content before baling, so that handling thereafter is simplified ; but unfortunately the baler shatters the leaves of dry crops and much is left on the ground. On a hot day the quantity lost may be considerably more in the afternoon than in the morning, and considerations such as these make field experience essential in deciding when to bale and what to do afterwards. As a rough guide it may be stated that hay is not fit to bale at all if there is any extrusion of moisture when it is twisted with the hands. Bales that are fit to collect into large stacks are springy within the strings.

Bales made by a pick-up baler may be scattered in singles all over the field ; collected together in heaps by means of a sledge drawn behind the baler ; or delivered directly into a trailer drawn behind. The first-named method has the advantage of requiring only one man for baling but uses the most labour in the end. Loads of bales are carried out of the field either with trailers or on buck-rakes. The best method of storing baled hay is under a barn, and if this is not available, thatching or covering of stacks with waterproof sheeting is essential.

SPECIAL METHODS OF HAY-MAKING

The beginning of making a crop into hay is assisted by taking advantage of a special weather forecasting service run by the Meteorological Office, but long-range forecasting is subject to error. Therefore, any method which requires only short spells of fine weather has an advantage. Tripod hay-making is one such method and barn drying is another.

Tripod Hay. Along with this method may be considered hay drying on wire fences, on hut racks and any other method of hanging partly dried hay clear of the ground in such a way that air can circulate through it.

If such appliances are loaded carefully and wet weather follows, a proportion of the rain runs off the outside of the crop rather than through it, and the amount of leaching is less than with hay on the ground. At least one of these methods, which uses hut racks, can be partially mechanised and there is also a special machine for loading tripods, but in general much hand forking is required and the labour requirement is high.

The details of construction of " tripods ", " quadpods " (formed from four poles instead of three), racks, etc., vary, but they usually consist of poles or frames about 8 ft. long which are leaned and fixed together in such a way that they stand 6–7 ft. high. When they are covered with hay there is a pyramid or wedge-shaped empty space around which the hay is disposed and although the thickness of hay may be 2–3 ft. in some places, the opportunity for it to dry is favourable. Each unit will carry about 5 cwt. of dry hay, and it is usual to erect about eight per acre.

Barn Dried Hay. In the discussion of artificial drying it was explained that the main drawback is the expense of evaporating a large quantity of water with purchased fuel. In field hay-making the drawback is the risk of qualitative and quantitative losses during natural drying. Barn drying is a compromise between the two. The objective is to remove about three-quarters of the crop moisture in the field and one-quarter indoors. Because moisture evaporates much more quickly from freshly-cut hay than from nearly-dry hay, it is usually possible to complete the field drying operation in two days and this improves the prospect of making use of short-term weather forecasting services to decide when to cut the crop.

In this country the first experience of barn drying was obtained with long or loose hay. More recently it has been found that with suitably designed equipment the process can be operated with rectangular bales made by a pick-up baler and this has reduced handling costs. It is the bale-drying method that is discussed below.

Field Drying. The field-drying part of the operation is conducted in the usual way, but instead of baling at about 25 per cent moisture content it is usually done at 35–50 per cent moisture content. At this stage full-sized bales weigh 70–100 lb. each, and some farmers prefer to modify their balers so that they deliver half-sized bales which are easier to handle. After baling, the crop is immediately collected and transported to the drier.

Batch Drying. Two common methods of barn drying are called " batch " drying and " deep storage " drying. In the former each batch of hay is stacked in the drier, is dried and is removed elsewhere for storage. In the latter the hay is introduced in layers, and after each layer is dried another is placed on top until the drier is full. There the hay remains until required for feeding.

Batch drying is suitable for hay containing up to 50 per cent of moisture. The size of batch to be dealt with at one time depends upon the floor area of the drier, each square foot of which will take about ½ cwt. of dried hay: thus one bay of a barn measuring 15 ft. × 24 ft. deals with a 9 ton batch. The floor usually consists of strong steel mesh, 3 in. × 3 in. square, through which air is forced by a fan. The floor is surrounded by air-proof walls rising to a height of at least 6 ft. and the bales of hay are stacked neatly into this space. The bales are laid on edge and alternate courses have their long axes at right angles to each other. So long as the total depth of hay does not exceed about 9 ft. (6 courses), drying should proceed satisfactorily provided the air flow is sufficient.

Ventilation. It is important that the ventilating fan should be capable of forcing about 45–50 cu. ft. of air per minute through every square foot of the floor. At this rate the air flow passes through the bales in sufficient quantity to keep them cool and to remove moisture from them.

The moisture extraction capability of the ventilating air varies inversely with its relative humidity, and since the relative humidity of air can be reduced by applying heat it follows that heated air removes water more quickly than unheated air. In the initial stages of drying, moisture can be removed more easily than in the later stages and, therefore, the need for supplying heated air increases as drying proceeds. There are many variable factors of which to take account in drier management, e.g. relative humidity of atmospheric air, moisture content of bales, time available before the drier is required for the next batch, volume of air supplied by the fan. Because of these factors it is advantageous to be able to alter air flow and heat supplied according to the conditions. Some plants are designed to raise the temperature of the ventilating air by 25° F. others by a less amount. Although the time taken to dry each batch is particularly affected by the ingoing moisture content it is generally possible in about five days.

Deep Storage Drying. Deep storage drying is most suitable for baled hay collected from the field at 35–40 per cent moisture content, although cases are on record of successful operation at higher moistures. It requires a ventilated floor, impervious sides and a copious flow of air in the same way as a batch drier but the air temperature rise is usually less and the air speed greater. The depth of loading is not more than 6 ft. at a time but as each layer is dried another one is placed on top until the final depth of hay may be about 18 ft., i.e. up to the eaves of the building. The advantage of storage drying is the reduction of handling due to drying and storing in the same place. One disadvantage is the necessity of providing a large area of ventilated floor.

The total labour required for storage drying is less than for field drying and even batch drying compares favourably with field drying. The reduced time during which the hay is in the field decreases the amount of tedding and turning and makes up for the labour of stacking bales in the drier and transferring them from there to the storage place. On the other hand the capacity of the drier may limit the volume of crop which can be dealt with at one time and for this reason it is advisable to start hay-making earlier and finish later than normal. Mid-season and late-harvested crops need not be mature and fibrous if they are taken from fields which have been grazed at well chosen times in the spring.

The cost of fuel for barn drying varies within wide limits according to the initial moisture content of the hay and the thermal efficiency of the plant. Most driers are either heated electrically or with oil heaters, and of these oil is the cheaper fuel although oil-fired equipment may be dearer to instal and maintain. Some driers are heated by coke which is the cheapest fuel of all. These have to be designed so that sparks cannot enter the air stream, as must the oil-fired type.

An important aspect of barn drying is the reduction of field losses as compared with conventional hay-making. It is usual to collect about 15 per cent more hay because less of the valuable leafy material is lost when baling at the appropriate moisture content. Feeding experiments have also shown that the feeding value of barn hay is superior to field-dried hay. The danger is that superior quantity and quality may be procured at too high a cost. In order to guard against this possibility it is necessary to ensure that the field machinery is well chosen, the plant well and cheaply designed and management directed towards extracting as much moisture as possible by wind and sun and as little as possible by artificial means.

The Economics of Barn Drying. The total cost of barn drying includes labour, fixed capital and fuel, all of which vary according to the design of the plant and method of operation.

Compared with field drying the labour cost of barn drying may be a little less, but for the present it is considered as equal and, therefore, needs no further discussion.

Capital investment is usually related to output : the greater the output per annum the less the capital investment per ton of hay produced. The relationship is likely to work out roughly as follows :

Annual output of hay. (tons).	Capital Investment should not exceed (£).
10	250
20	400
50	900

With plants capable of producing 100 tons per annum an investment as low as £10 per ton has been quoted in some cases. Taking an average from efficiently run plants and allowing for depreciation it is probable that the fixed costs amount to about 30*s*. per ton of hay produced.

Fuel cost is tremendously affected by management, and the basic reason is illustrated by the following figures which show the amounts of water to be removed from the crop at various moisture levels.

Moisture Content before barn drying (per cent).	Weight of water to be removed to produce 1 ton of dried hay at 15 per cent moisture content (cwt.).
60	22½
50	14
40	8¼
30	4¼

It is obviously necessary to reduce the moisture content to 45 per cent or less in the field in order to reduce drying time and cost. With material at 30–35 per cent moisture content the cost of fuel will probably be less than 20*s*. per ton of dried hay : at 50 per cent moisture it may be 60–70*s*. per ton. With a well-designed plant, operated intelligently, it should be possible to average about 30–35*s*. per ton of hay for fuel. Thus, excluding labour, the total cost (fixed cost plus fuel) would be about 60*s*. per ton more for barn hay than for field hay if the same quantity were collected by each method. But it should not be forgotten that for every ton of barn hay there would probably be only 17½ cwt. of field hay (due to the higher losses). In effect the extra 2½ cwt. is obtained at a cost of 7*s*. 6*d*., and if it is worth (say) 37*s*. 6*d*. (at £15 per ton) the difference of 30*s*. may justifiably be deducted from the total cost, thus giving a net cost of about 30*s*. per ton more for barn hay than for field-dried hay.

ENSILAGE

Silage can be made from a wider range of crops than dried grass or hay : any crop which is suitable for feeding to livestock in its natural state, and which contains sufficient moisture and sugars to produce the necessary fermentation, is usually suitable for making into silage.

Grass Silage. Grass silage is by far the most important and will be considered first. For the present purpose it includes pure grasses, pure legumes (such as lucerne) and mixtures of the two either in the form of temporary or permanent swards.

The main objectives are to collect the crop at a nutritious stage ; to deal with it in such a way that field losses and in-silo losses are minimised, and to achieve a type of fermentation which results in a palatable product of high feeding value. Silage is preserved by organic acids which are produced by fermentation of the sugars contained in the cell sap. If the sugars are plentiful a beneficial lactic fermentation takes places : if they are scarce, other undesirable types of fermentation may occur, the most common of which leads to the formation of butyric acid. Grasses contain more sugar than legumes and mature plants more than immature plants. Hence young and mainly leguminous crops are more difficult to make into good silage than older and mainly grass mixtures. A desirable type of fermentation is also encouraged, within limits, by a reduction of the water content of the crop and by chopping or laceration.

Wilting. One of the important skills necessary for making good quality silage is an ability to recognise the conditions liable to lead to a poor type of fermentation, together with knowledge of the appropriate corrective action. When the objective is to make nutritious silage early in the season the most common difficulties are too much water in the herbage and too low a concentration of sugars. In this case it is often only necessary to correct the former because a reduction of water content automatically increases the concentration of the cell sap. For example, a leguminous crop containing 20 per cent or less of dry matter is much improved for ensilage if it is wilted for 24 hours, during which the dry matter content may rise to 25 per cent or more. Experiments have shown that the quality of the silage is almost invariably improved and at the same time the in-silo losses are reduced.

Molasses. Should wilting not be possible, the necessary conditions may be obtained by the addition of a sugar solution in the form of molasses, which is a by-product of the sugar refining industry. The usual rate of application for leafy young grass is 2 gallons molasses diluted with 2 gallons water per ton of grass ; half as much again should be used if the crop is a pure legume.

Preservatives. An alternative to providing sugar for fermentation is the addition of a chemical preservative to inhibit fermentation. Sodium metabisulphite and calcium formate preparations are available in powder form : both will give good results so long as they are used at the recommended rates and distributed evenly through the mass of silage. They have the advantage over molasses of being easier to handle and forage harvesters can be equipped with mechanical " applicators " which mix the powder with the crop most efficiently.

Losses in Silage Making. There is always a substantial loss of food material between filling a silo and taking out the silage, the three chief sources being the fermentation energy dissipated as heat and carbon dioxide ; the waste products of putrefaction, some of which have to be discarded from the outsides of the silage before feeding ; and the effluent liquid which drains away as the herbage is consolidated.

Under good conditions in walled clamps the total loss may be about 25 per cent, of which 1 per cent may be due to effluent liquid, 5 per cent the tangible products of putrefaction, and the rest due to fermentation of various kinds. In practice total losses as high as 40 per cent and as low as 15 per cent have been measured, the former often associated with unwalled clamps out of doors and the latter with specially designed and roofed structures.

Temperature Control. When grass is deposited in a heap it continues to respire and generate heat so long as it has access to a supply of oxygen. The quantity of oxygen will be increased if it is dry and loose and decreased if it is wet and consolidated, so that the farmer has a ready method of temperature control. If the temperature is allowed to reach and remain above 120° F. for very long, the result will be a sweet smelling brown silage. This is palatable to stock but of low feeding value—partly because a large proportion of carbohydrate has been used up in the heating and also because the high temperature reduces the digestibility of the protein.

It has been recommended in the past that the objective should be a temperature of about 90–100° F., but recent experimental work has suggested that under favourable conditions the temperature should be kept as low as possible by quick filling and efficient consolidation. However, there still appears to be some doubt whether a low temperature is advisable at high moisture contents. To state the case rather differently, it is probable that the more important cause of poor quality silage is not the low temperature *per se* but the high water content which is often associated with it.

Method of Cutting. A crop intended for silage may be cut either with a hay mower type of knife bar or the rotating flails of a forage harvester. In the former case it may be transported to the silo as *long* material either with or without a preliminary wilting period, or it may be picked up from the swath with a flail harvester or a crop chopper. Crops cut with a flail may be transported as *flailed* (lacerated) material or the primary machine may both flail and *chop* at the same time before delivery to the transport vehicle. From the foregoing methods it is obviously possible to select many different combinations, but the resultant products fall into three broad groups, i.e. " long ", " lacerated " and " chopped ". Because the last two groups involve more damage to the individual plants there is a smearing of the cell sap through the mass and this usually leads to a better fermentation.

Silos can be filled with chopped material by means of a tractor-driven blower but long and lacerated material cannot be dealt with in this way. It has to be moved with hand forks, elevators or buckrakes, all of which involve more labour than a blower.

Type of Silo. Silage can be made in unwalled clamps or stacks, temporary or permanent walled clamps, tall box silos or tower silos. Stacks are usually situated in the open ; walled clamps may be outside or under cover : box or tower silos are always roofed. Efficiency of conservation usually increases in the order in which the silos are named above, efficiency being improved by exclusion of air from the mass and protection from the weather.

Stacks have gradually become less popular owing to their high labour requirement, the usual method being hand forking into an elevator and hand building. Draw-over clamps without walls, or bunker silos (walled clamps), are filled with long or lacerated grass and are the most numerous. If the clamps are large enough it is possible to draw trailer loads over, but such a practice is always difficult and often dangerous, especially on narrow clamps, and the task is better done with a buckrake. Even a buckrake can be dangerous unless the tractor is always driven backwards up the slope and is kept sufficiently far from the sides when the contents reach above the height of the retaining walls. Boxes and tower silos are particularly suited to chopped grass and are usually filled with a forage blower.

Covering the Silo. Two of the details that are frequently given insufficient attention on farms are the disposal of effluent liquid and the methods of covering the silage and protecting it from the weather.

Unless it can be guaranteed that the crops will always be dry enough to eliminate seepage (i.e. 30 per cent dry matter or over) it is essential to provide adequate drainage. Young herbage ensiled without wilting may easily produce liquid to the extent of 15 gallons per ton and account must be taken of the fact that if this is discharged into watercourses it may lead to serious pollution, for which the farmer may be called to account.

Finishing off a silo implies protection against leaching by rain and against oxidation by air. Weather protection may be achieved by a variety of obvious means, including coverings of soil, dung, plastic sheeting or roofing materials. The exclusion of air is assisted by covering with plastic sheeting which is applied as soon as possible after filling and held in place by materials such as ground limestone, sawdust, straw bales, etc. Air should also be prevented from filtering in at the sides by filling cracks in the walls. Such methods are worth while with indoor as well as outdoor silos except those that are gas-tight in construction.

Other Types of Silage. Mixtures of oats and vetches, or oats and peas, or beans, vetches and oats, are still grown specially for silage in some parts of the country, but the practice is dying out. With the exception of maize, which is specially grown for the purpose, it is mainly waste products which are ensiled today.

Maize. The National Institute of Agricultural Botany has classified maize varieties according to their suitability for silage making in different parts of the country. It is recommended that the crop should be harvested when the seeds are at the " soft dough stage ". It is essential to chop or severely lacerate the crop in order to achieve the necessary consolidation, and maize harvesting attachments are available for forage harvesters : otherwise maize is treated in the same way as grass and very palatable silage usually results (see also p. 294 and Appendix V).

Pea Haulms. This valuable by-product is available when peas are harvested green for human consumption. The whole plants are collected and passed through the shelling machine or " viner " in which the peas are separated ; the residue consists of broken stems, leaves and empty pods. This material does not need molasses or other additions in order to make good silage and the procedure is the same as for grass silage.

Beet Tops. These must be clean, otherwise feeding the silage will result in digestive disturbances. The tops can be ensiled either whole or chopped and there is no necessity to add anything or to encourage heating. A large volume of effluent liquid must be allowed for and its disposal may present problems.

Wet Beet Pulp. All that is necessary is to make a heap and exclude air as soon as possible with a weighted plastic sheet or other suitable material such as a layer of soil.

Surplus Potatoes. If they are cooked first, potatoes may be treated in the same way as wet beet pulp : but if they are uncooked they cannot be ensiled by themselves. On the other hand they can be introduced in shallow layers into grass silage if they are available at the right time of the year : the heat engendered during fermentation of the grass partly cooks and preserves the potatoes.

Kale, Rape, Cabbage. These crops need to be chopped or lacerated. There is no need for additives or for heating to occur in the silo. Stock do not usually find kale silage as palatable as grass silage and it is not recommended that cruciferous crops should be grown specially for the purpose but only ensiled when they would otherwise go to waste.

Feeding Silage. Silage feeding methods come under two main headings, either (*a*) the cattle go to the silage and help themselves (*self-feeding*) or (*b*) the silage is taken to the cattle or sheep (*rationed feeding*).

For self-feeding it is desirable that the quality of the silage should be uniform in order to avoid any tendency for relatively unpalatable layers to be refused. The settled depth of silage should be about 5–6 ft. so that animals can reach to the top but not over the top. A suitable feeding fence should be placed between the cattle and the silage and moved forward as the silage is consumed : it should be so constructed and managed that silage is not pulled to the floor and trodden underfoot.

The number of animals must be adjusted to the width of feeding face so that they do not need to bully each other in order to eat to appetite. The width per beast will depend upon the length of time allowed for feeding, and the minimum is about 6–9 in. in the case of animals with continuous access for 24 hours per day.

The floor of a self-feed silo should be of concrete and should slope away from the silage face. It should have provision for disposal of the slurry which is inevitable and copious. Attempts to soak up the slurry with straw usually fail and it is better to plan at the beginning to keep the area in front of the silage clean. If the water trough is at a distance from the silage face the slurry problem seems to be reduced a little.

One simple but very important principle is occasionally overlooked, i.e. the necessity of providing sufficient silage for animals which are allowed to help themselves : dairy cows of the larger breeds may eat from ¾ to 1 cwt. per day.

When silage is carted to the stock the method of removal from the silo varies according to the conditions in which it has previously been ensiled. Long and lacerated silages need to be cut vertically before they can be forked out, and although there are various mechanical devices for the purpose few have any advantage over an ordinary hay knife. Chopped materials score in respect of the ease with which they can be removed mechanically. For example, silage that has been chopped very short will flow through mechanically driven augers or it can be removed with a tractor fork.

Feeding Value of Hay and Silage. In the past a great deal of emphasis has been placed on the value of silage making as a conservation process and it has often been compared with hay-making to the latter's detriment. But the fact is that the two methods are complementary rather than competitive and each is capable of producing first-class fodder by following the correct methods.

It is not usually possible to make hay in the field as early in the season as silage, but when hay is barn dried at the " silage stage " it appears to be at least as good as well-made silage and sometimes better. When comparisons have been made between barn-dried hay and silage, both of which were cut from the same field on the same day, it has been evident that both sheep and cattle found the hay more palatable—appetite being measured by the consumption of dry matter on *ad. lib.* feeding. The hay also had a lower fibre content in the dry matter and a higher digestibility. With bulky fodders palatability is an important factor, and just as cattle find barn hay more palatable than silage, so they find high dry matter silage more palatable than low dry matter silage.

If field-made hay could be collected at the same growth stage as silage there seems no reason why it should not be just as nutritious, and it has not been possible to distinguish in feeding trials between barn hay and field hay made in good weather. On the other hand, hay that has been badly weathered will certainly have a comparatively low feeding value.

All these considerations lead back to the original postulate that management is more important than method, and that bad management can spoil a good crop but good management can never improve a bad one : it can only prevent further deterioration.

Chapter XIII

FUNGUS AND VIRUS DISEASES OF CROPS

THERE is no clearly defined boundary between a healthy and an unhealthy condition in plants. In practice, yield is a common criterion of good health, for it is generally recognised that a large crop cannot be produced when the plants composing it are in an unhealthy condition. The causes of unhealthy crops and low yields are many and varied, but the more important are these : the land may be in poor heart and the standard of fertility low ; the soil may be sour or badly drained and in an unsatisfactory physical condition ; an ample supply of food materials may be lacking, or some one essential plant nutrient may be absent, or present in a form in which it cannot be absorbed. Then there is the weather, for periods of drought or excessive rain may intervene and check plant growth.

Apart from all these considerations, however, the crop may be *diseased.* If the damage caused by the depredations of insect pests and eelworms is excluded, the main agencies of disease are fungi and certain extremely minute disease agents called viruses.

THE NATURE OF FUNGI

The fungi are a lowly group of plants completely lacking in chlorophyll, the green colouring matter of other plants. As a consequence they cannot build up the food required for their growth from the simple plant nutrients in the soil and the carbon dioxide of the air. To live they require, therefore, a ready-made supply of complex organic foods, such as carbohydrates and proteins. The main sources from which they obtain these are either living plants or their dead remains.

Parasites and Saprophytes. The fungi thus fall into two groups, namely, *parasites*, those dependent on a living host, and *saprophytes*, those able to feed on dead plant tissues. It should be noted that this distinction, though useful, is not an absolute one, for some fungi bridge the gap by living saprophytically for a time and then becoming parasites. A fungus of this nature is *Botrytis*, species of which cause the well-known Chocolate Spot disease of field beans.

From the farmer's point of view the fungi parasitic on plants naturally seem to be the most important, but without the saprophytes there would be no agriculture, for they play an essential part in breaking down and returning to the soil and air the materials locked up by the growth of previous generations of plants. Their activity in this direction has its troublesome side when it is responsible for the decay of timber used in farm buildings, gateposts, stakes, etc. Much of this can be prevented, however, by the use of suitable wood preservatives.

The Mycellum. Structurally, the fungi are far simpler than all other plants, with the exception of the algæ. The fungus body is (with rare exceptions) built up of very minute, thin-walled, branching threads or *hyphæ*, collectively known as the *mycelium*. It may be so small that it is invisible to the unaided eye, or the individual strands may be matted together to form large conspicuous bodies, as in mushrooms, toadstools and puff-balls.

Spores. Fungi reproduce their kind by means of spores, but these are so small that they can be seen only with the aid of a microscope. They may be formed either vegetatively or by the simple abstriction of the tip of a fungus thread or by its division into a chain of spores, or again, as the result of a sexual process. Most fungi produce two or more forms of spores which are often so unlike one another that, before the complete life cycle of the fungus was discovered, the different stages of development were classified in totally different groups. These various forms of spores fall into two broad categories, namely those responsible for the rapid multiplication of the fungus, and those by means of which it tides over periods of adverse climatic conditions or contrives to persist in the absence of the host plant. Those of the former group, often popularly called " summer spores ", are usually short-lived and their life is very dependent upon weather conditions. For instance, a short spell of dry weather in the summer may result in the wholesale destruction of the spores of *Phytophthora infestans*, the fungus responsible for Potato Blight, whilst damp muggy conditions will favour their development. Spores of the latter group, sometimes called " winter spores ", usually result from some form of sexual process, and they often have a lengthy period of life even under conditions inimical to growth. Their walls are commonly thick and dark in colour, or, where this is not the case, they are enclosed in resistant spore cases. Some fungi, however, form *sclerotia*, bodies which consist of hard compact masses of mycelium which are capable of surviving in a dormant state for many years. A fungus of this kind is *Sclerotinia trifoliorum*, the cause of Clover and Bean Rot. The spores of the different kinds of fungi vary in size and shape, but they are all very minute and are produced in enormous numbers. The spores of the Bunt fungus are comparatively large, but a single bunted ear of wheat may contain 250,000,000 of them.

The dispersal of fungus spores is effected mainly by air currents, and at some seasons of the year, except after heavy falls of rain, the air is full of them. In addition to this mode of distribution, the spores of some fungi adhere to the coats of grain and seeds, and it is these which cause the so-called " seed-borne " diseases, such as the Smuts of cereals. It should be noted, however, that not all the Smuts are caused in this way for some, as will be seen later, are due to the presence of mycelium deeply embedded within the grain. Spores are also dispersed by rain, and by insect agency, and examples of these will be given in due course.

Method of Attack. Parasitic fungi gain an entrance to the tissues of their host plants in various ways. Some are only capable of attacking them at the seedling stage, so that once this is passed there is no likelihood of the plant becoming diseased. More generally, though, the spores germinate on the surface of a leaf, stem or young twig, and give rise to fungus threads which either penetrate between the guard cells of the stomata or bore directly through the cuticle. Other fungi, however, are incapable of attacking sound and healthy tissues, and to gain an effective entry into their hosts the spores must germinate on wounds (Fig. 58c). These "wound parasites" are often very troublesome to the fruit grower for they cause such diseases as Apple and Pear Canker (*Nectria galligena*), and the Silver Leaf disease (*Stereum purpureum*). Once an entry has been secured the hyphæ spread either between the cells of their host plant, so forming an *intercellular* mycelium, or by boring directly through them, that is, growing *intracellularly*. In the former case the actual contact of the fungus with its host's food supply is effected by means of button-like or branching suckers, or *haustoria* (Fig. 59). The penetration of the tissues does not necessarily result in immediate and obvious damage to the plant. It may, indeed, have no visible effect for some time as, for instance, in the case of Bunt of wheat, where infection which occurred at the seedling stage does not become apparent until harvest time.

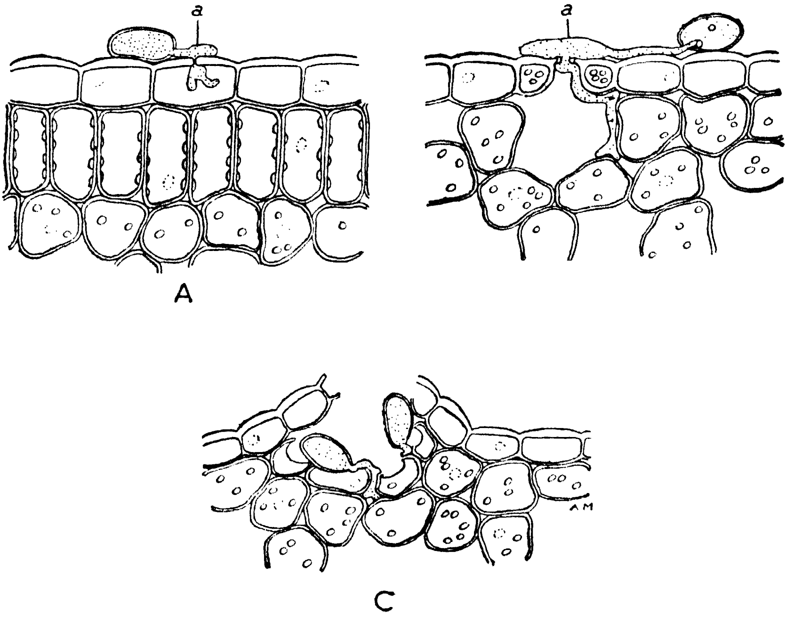


Fig. 58.—Fungus Threads attacking Plant Tissue.

A, germinating spore penetrating an epidermal cell.
B, germinating spore penetrating stoma.
C, spores germinating in wound.
a, appressorium.

The irritation set up by fungus organisms penetrating into plant tissue often acts as a stimulus to the further growth of the infected tissues, and galls or tumour-like outgrowths are formed. This occurs in Wart disease of potatoes (*Synchytrium endobioticum*) and Club Root of turnips and swedes (*Plasmodiophora brassicæ*). Many fungi, however, do not gradually drain their host plants of foodstuffs, but bring about the immediate death of the cells with which they come into contact. The track of their mycelium is then marked by brown dead tissues, as it is in the case of barley infected with the Leaf Stripe fungus, *Pyrenophora graminea.*

Specialisation. The fungi show great specialisation and are generally only capable of attacking either a particular host plant or a limited range of closely allied plants. Some of them, especially those responsible for the " rust " diseases of cereals and grasses, are very specialised indeed, for they exist in many strains with sharply limited infective capacities. This extreme physiologic specialisation prevents their indiscriminate spread amongst cereal crops and wild and cultivated grasses. Where the specialisation is less marked the parasites are generally confined to the limits of a particular Natural Order. Thus the fungus responsible for the Club Root disease of swedes and turnips is capable of attacking many other cruciferous plants, or again, Blight of the potato may occur on other members of the Solanaceæ, but neither can infect plants outside of these two groups.

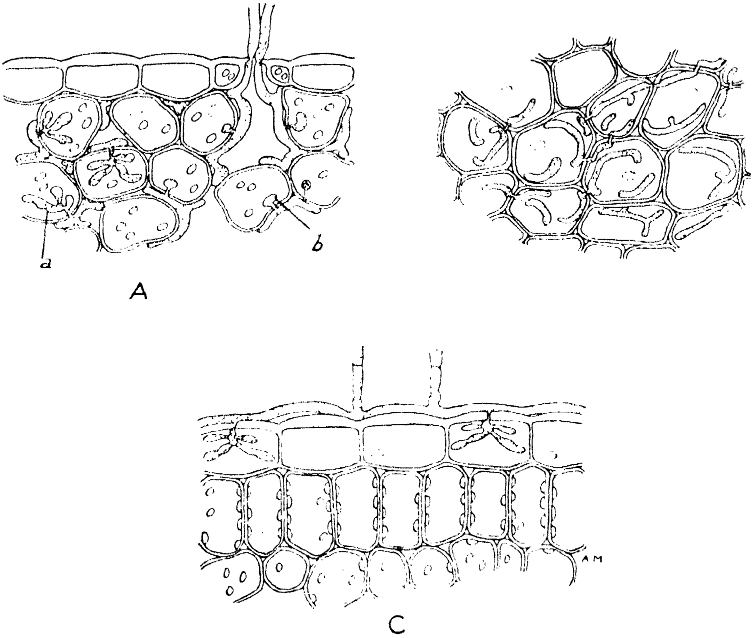


FIG. 59.—DIFFERENT TYPES OF HYPHÆ.

A, intercellular hyphæ showing penetration of haustoria into cells : (*a*) branched, (*b*) knob-like haustoria. B, intracellular hyphæ.
C, superficial hyphæ with haustoria penetrating epidermal cells.

The extent to which fungi attack their host plants, or the intensity of an outbreak of disease, is largely dependent on the environment. The conditions both of the soil and of the atmosphere play an important part. As a rule crops growing in the most fertile soils are those which are most badly attacked. When growth is forced, and the leaves and stems are luxuriant and sappy, plants are usually more susceptible to parasites. Thus a too liberal use of nitrogenous manures, in attempts to produce exceptionally heavy crops, may defeat its purpose by inducing a severe attack of some fungus disease. The judicious use of potassic and phosphatic fertilisers, on the other hand, tends to render the plant more resistant to disease. It has long been known that a sour condition of the soil, easily remedied by the use of lime, is favourable for the development of the soil-inhabiting Club Root fungus, and consequently for outbreaks of the disease.

Deficiency Diseases. Unhealthy conditions of crops may arise, however, without the intervention of any parasite. If the food requirements of the plant are inadequate, or if certain essential plant nutrients are not available, symptoms of starvation may appear. These ailments are usually referred to as " deficiency diseases ". Thus when crops suffer from nitrogen, potash or phosphate starvation, there are signs of ill-health. Apart from any deficiency of major plant foods, however, diseased conditions may arise if certain other essential nutrients are lacking and, in recent years, it has been discovered that when salts of boron or manganese are not available in the soil certain well-defined symptoms of disease appear. For instance, a soil deficient in available boron may lead to Heart Rot and Dry Rot in the sugar beet crop, and a deficiency of manganese to a debilitating disease known as Speckled Yellows. These conditions can be remedied by an application of the appropriate salts, but expert advice should always be sought before applying these (see pages 22, 24).

Influence of Weather. The fact that weather conditions largely determine the extent to which crops are attacked has been recognised from the earliest historical times. Indeed it was not until the fact had been established that fungi could be the direct cause of plant diseases that the view was abandoned that the weather was solely responsible for epidemics of disease. Parasitic fungi do not all require precisely the same conditions for optimum development. Moist weather is favourable for the spread of most of the serious plant diseases occurring in this country, but some fungi, such as the Powdery Mildews, thrive best in dry seasons. Although moisture is necessary for the germination of fungus spores, the process does not require long periods of wetness, and a film of dew, lasting for a few hours only, is usually sufficient for most spores to start growth and gain an entry into the tissues of their hosts. Temperature, too, is important, partly because high temperatures may lead to the desiccation and death of thin-walled spores and partly because their germination takes place only within certain limits. Much progress has been made in reducing the enormous losses caused by plant disease, and this is largely because the life cycles of many important fungus parasites have now been worked out in detail, and information gained on the environmental conditions which are suitable or unsuitable for their development.

THE CONTROL OF PLANT DISEASES

The methods in use for controlling fungus diseases of plants are for the most part preventive rather than curative. Once the mycelium has established itself it is, in most cases, more or less deeply embedded in the tissues of the host and so out of reach. A cure consequently would necessitate a surgical operation which, though possible in the case of infected tree branches, which can easily be cut out, is out of the question where crops of herbaceous plants are concerned. A detailed knowledge of the life histories of parasitic fungi is particularly valuable when attempts are being made to devise methods for preventing the diseases which they cause, as it usually reveals the stage of growth at which measures can be applied with the best chances of success.

Disinfection of Seed. Thus, if it is known that a disease is caused because the spores of some specific parasite are present on the seed coat, then the organism can be killed by treating the seed with a suitable fungicide before sowing. These fungicides, or seed disinfectants as they are called, are now widely used, and by their use many important diseases of crops, especially the cereals, are prevented. It should be noted here that although a sample of seed corn may appear clean to the unaided eye it does not necessarily follow that this is so because, when examined under the microscope, spores causing the following diseases may be found. Wheat may be contaminated with Bunt (*Tilletia caries*), and barley affected with Covered Smut (*Ustilago hordei*) or Leaf Stripe and Net Blotch (*Pyrenophora graminea* and *P. teres*). As for oats, these may carry the spores of Covered Smut (*Ustilago hordei*) and Loose Smut (*Ustilago avenæ*), and in addition Leaf Spot (*Pyrenophora avenæ*). On rye the Stripe Smut fungus (*Urocystis occulta*) and Bunt (*Tilletia caries*) may be present. These are all seed-borne diseases and the enormous losses which they used to cause are now prevented by modern methods of seed disinfection. The beneficial practice of seed disinfection is not confined to the cereals, however, for there are other diseases of agricultural and horticultural crops which are seed-borne and, when this is the case, the appropriate methods of seed disinfection can often be practised.

Starving Out Harmful Soil Fungi. When disease arises from the presence of soil-inhabiting fungi, however, seed disinfection is of no avail. In this case the organism must be starved from the soil by ceasing to grow the host plants for a period. The time that this will take depends upon the nature of the parasite concerned ; in some cases a year will suffice, but in others a much longer period will be required. In these circumstances, therefore, it is clear that the sequence of cropping must be modified, and susceptible crops omitted. Weeds, too, must be suppressed because some of these may harbour the parasite and enable it to linger on from year to year. It is, unfortunately, still not generally realised that if the same crops are grown too frequently on the same land disease is likely to appear, yet this is the case. When red clover is grown too frequently on the same field, the crop sickens and Clover Rot (*Sclerotinia trifoliorum*) gains a hold ; similarly when land is corned too heavily, Take-all and Whiteheads (*Ophiobolus graminis*) usually appear.

Spraying and Dusting. Seed disinfection, and a well-planned sequence of cropping, however, are no protection from airborne spores. It is no simple matter to control diseases which arise in this way for their prevention involves either the application of protective spray fluids, if this procedure is economic, or the use, if they are available, of varieties resistant to attack. In horticultural practice the direct prevention of pests and disease by spraying or dusting a crop with insecticides and fungicides is a routine measure, but practical and economic considerations limit their use in farm practice. Fungicides are applied, however, to potatoes to prevent Blight (*Phytophthora infestans*), and to celery to reduce the losses caused by Leaf Spot (*Septoria apii-graveolentis*). In recent years the development of new fungicidal and insecticidal sprays, and new methods of applying them, has received considerable impetus.

Resistant Plants. In addition to this method of attacking plant parasites, another means of avoiding the losses they cause is being sought in the raising of plants capable of resisting, either partially or completely, those species which normally attack them. The possibility of this is dependent upon the fact that most of the crop plants, when exposed to infection under uniform conditions of growth, show very different degrees of susceptibility, some even proving immune. This capacity of resisting the disease is known to be inheritable, as a rule in a simple Mendelian manner, and thus the building up of new resistant varieties has become practicable.

Prohibition of Imports. One other aspect of the problem of controlling the fungus diseases of plants has received much attention of late years. The fact has been recognised that widespread as many of the important ones already are, all of them are by no means universally distributed. Many countries, for instance, though growing potatoes, know nothing of Wart disease or even of Blight. It may be that local conditions are unsuitable for the growth of the particular fungus or, on the other hand, its absence may be due to the fact that it has, so far, failed to reach that country.

There is clearly much to be said for trying to prevent the introduction of new diseases, especially when it is realised that in their first appearance they are often very destructive. This is possible by regulating the movement of plants or seeds likely to carry them. Most countries now have legislation designed for this purpose, and require the inspection and certification for freedom from pests and diseases of plants intended for export and import, and the provision of health certificates. Each country has its individual problems and requirements, and these may on occasion involve complete prohibition or seasonal prohibition of certain plants or produce according to the countries of origin. In this country the Destructive Insects and Pests Acts have from time to time prohibited the importation of a comparatively small number of specified plants. They also prescribe the measures to be used in checking the spread of a number of new or newly introduced pests.

CLASSES OF FUNGI

There are four main classes of fungi :

Phycomycetes,	Basidiomycetes,
Ascomycetes,	Deuteromycetes.

This classification is based on the method of spore formation. In most Phycomycetes spores are formed in *sporangia* at some stage in the life cycle, in the Ascomycetes in *asci*, and in the Basidiomycetes on *basidia*. In the Deuteromycetes or Fungi Imperfecti, there are no sporangia, asci or basidia in the life cycle so far as is known, and only asexual spores, chiefly conidia, are formed. Another class of organisms, the Actinomycetes, is not grouped with the fungi because of its closer relationship to the bacteria, but mention of it is made, as it contains *Streptomyces scabies*, the organism causing Common Scab of potato.

In the following section the life cycles of a number of parasitic fungi are described, together with the symptoms of the diseases they cause and the methods used in controlling their spread. Many important species have been omitted, and those dealt with have been chosen largely because they provide examples of the various methods in use for the control of plant diseases. Before proceeding with fungi, however, it would be appropriate to give an account of a disease caused by an Actinomycete.

Common Scab of Potato (*Streptomyces scabies*). Probably the commonest of all potato diseases, Common Scab is seen on the tubers at lifting time as unsightly scabs resulting from the production of loose corky tissue by tubers in resisting invasion by the parasite. Infection is usually superficial, but various forms of scabbing may occur, including the deeper pitting of the tubers. This may be because of the existence of different strains or species of *Streptomyces*. Although usually most noticeable on the tubers, all other below-ground organs are susceptible to attack. The internal flesh of the tubers, however, is not affected.

The causal organism, *Streptomyces scabies*, possesses very slender, sparsely septate, simple or much-branched filaments, and from these arise aerial hyphal branches that terminate in a characteristic spiral twist. It is here that sporulation takes place by fragmentation of the filament progressively from the tip backwards. Infection occurs through lenticels and small wounds, and may take place at the earliest stages in the development of the tuber and continue as long as growth of the tuber is still taking place. The organism is soil-borne, and especially prevalent on light, gravelly soils low in organic matter, and on freshly broken land. Although Scab may sometimes be very severe after newly ploughed up grass, the level of attack often becomes negligible after several years of arable cultivation. Severe attacks often follow hot, dry summers, and may arise on land that has received heavy applications of lime, ashes or other alkaline substances.

Control Measures. Effective reduction in the disease frequently follows the making up of a deficiency of organic matter in the soil by the ploughing in of a green crop or, on a garden scale, by the incorporation into the soil of fresh organic matter such as grass mowings before planting. On soils already alkaline, further addition of lime, ashes or other alkaline material should be avoided, and the more acid fertilisers used, such as sulphate of ammonia.

On soils favourable to Scab, the interval between successive potato crops should be as long as possible. On such soils, provided at least four years have elapsed since the previous potato crop, beneficial results have been obtained in recent years following the disinfection of affected seed tubers before planting, by dipping them in certain proprietary organo-mercury fungicides. Badly scabbed tubers may, however, have sustained injury to the eyes and if used for seed a gappy, unprofitable crop may well result. Such seed is best chitted in boxes before planting.

DISEASES CAUSED BY PHYCOMYCETES

Club Root of Swedes and Turnips (*Plasmodiophora brassicæ*). Until recently it was usual to classify the organism causing Club Root, or Finger-and-Toe as it is sometimes called, with the slime fungi or Myxomycetes, but it is now included in the Phycomycetes. It is completely lacking in the mycelium characteristic of most fungi and consists instead of masses (plasmodia) of much-nucleated protoplasm with no defining walls. The plasmodium breaks up into small spherical spores, which on germinating produce amœba-like bodies capable of changing their shape and travelling by a slow creeping movement. *Plasmodiophora brassicæ* attacks only those plants belonging to the Cruciferæ. Swedes, turnips, rape, cabbage, brussels sprouts and mustard are the crops most commonly affected, but weeds such as charlock, wild radish and shepherd's purse are also attacked (Fig. 60).

The symptoms of Club Root are irregular masses of nodule-like swellings on the root system. These remain firm during the summer months, but as the autumn advances they decay and form a foul-smelling brown mass. The plasmodium of Club Root cannot be seen by the unaided eye, but it can be demonstrated by the use of appropriate staining methods and the aid of a microscope. It occupies abnormally large cells, the contents of which, in unstained preparations, appear to be normal. Towards the end of the summer the plasmodium in the " giant cells " gives rise to small rounded spores. When the diseased tissue decays these are set free and contaminate the soil. On germination the spores give rise to minute bodies which are able to move about in the soil water. These spores and the slow-moving amœboid-like bodies into which they subsequently develop bring about the infection of the root hairs of susceptible plants. Once inside the root the fungus increases rapidly in bulk, and it may subdivide to form more than one plasmodium in a cell. As fresh cells are penetrated they are stimulated to further development, forming giant cells and the mass of gall-like growths.

Control Measures. Club Root is very prevalent on soils which are deficient in lime, especially if these are waterlogged or badly drained. Its occurrence is usually as reliable an indicator of lime shortage as the presence of spurrey or sheep's sorrel. The only direct approach towards controlling the disease is by the improvement of drainage and the application of lime to the soil. Freshly slaked burnt lime, hydrated lime or ground quick lime are best. Ground limestone, chalk and other forms of lime are not so good. It should be given as soon as the crop is cleared, but it must be applied in a finely divided state and well incorporated into the soil. Where Club Root has been troublesome, however, it is wise to seek advice before applying lime because, if it is applied in excess, it may pave the way to other troubles. On soils subject to Club Root the use of superphosphate and sulphate of ammonia is inadvisable ; instead, basic slag or ground mineral phosphate, and nitro chalk or nitrate of soda should be used.

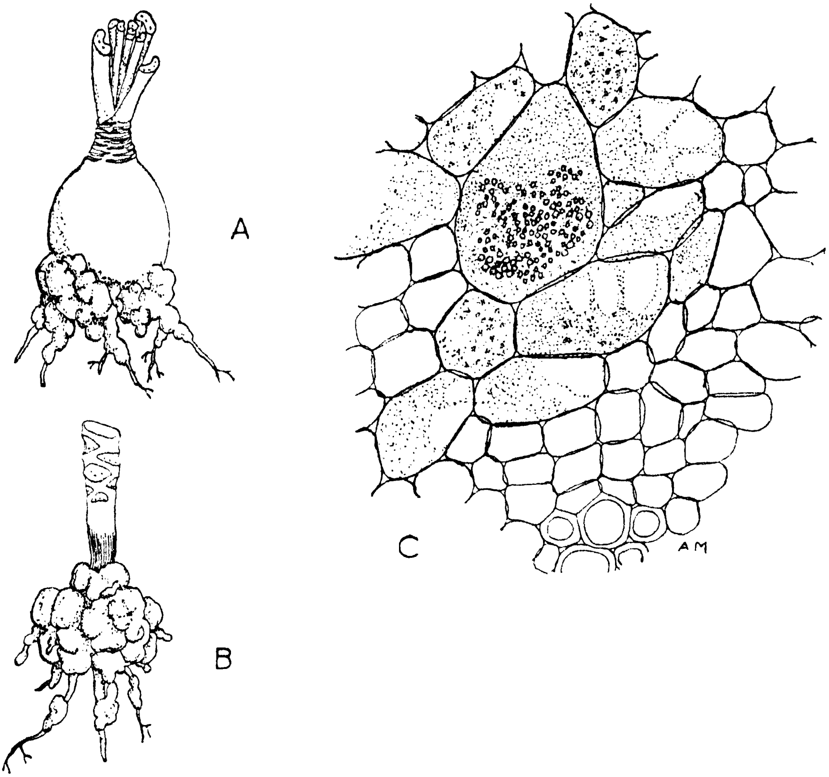


Fig. 60.—Club Root (*Plasmodiophora brassicæ*).
A, swede, B, cabbage, affected with Club Root.
C, enlarged section of diseased root showing giant cells and stages of spore formation.

Where possible the roots of all diseased plants should be burnt. This can be done in gardens and small holdings, but it is usually impracticable where susceptible crops are grown on an extensive scale. In farm practice, therefore, precautions should be taken to limit the spread of the parasite, and then to remedy the condition of the affected field. Great care should be taken in the disposal of an infected crop. If the roots are used for feeding in yards, fragments of diseased material may fall into the litter and so find their way to the manure heap, and in this way clean land may become contaminated. If the roots are fed on grassland, however, there is less chance that the disease will be spread. All cruciferous plants which are bought for transplanting should be carefully examined for the presence of Club Root, and any which show signs of disease should be burnt. None but perfectly healthy plants should be used for transplanting. It should be noted in this connection that under the Sale of Diseased Plants Orders, 1927–1952 and the Sale of Diseased Plants (Scotland) Orders, 1936–1953, plants substantially affected with Club Root may not be sold for planting purposes. On transplanted crops, a good control can be obtained by dipping the plants in a mixture of 1–2 ounces of pure calomel to 1 pint of water. On land where the disease has appeared in severe form, as long a period as possible should elapse before a susceptible crop is again grown.

So far, none of the commonly grown cruciferous crops has been found to be immune to Club Root, although the yellow-fleshed, purple-top turnip called the Bruce and grown in Scotland for many years possesses a high degree of resistance. Some varieties of swedes, too, including the purple swede Coxton Crofter and the green swedes Wilhelmsburger, Teviotdale and Drummond's Disease Resisting, have shown a high degree of resistance in trials in this country. The constant selection inherent in seed multiplication of swede varieties, however, can result in changes in detailed varietal characters and the degree of resistance can, in consequence, vary according to the seed source. It is known too that physiological races of *Plasmodiophora brassicae* exist, and these might conceivably result in differential reactions according to the variety of the host. Of the brassicas used for forage crops, kale is probably the least seriously affected.

Powdery Scab of Potato (*Spongospora subterranea*). All below-ground portions of the plant are subject to attack, but there is little adverse effect except on the tubers, on which the disease occurs most commonly as circular scabs. These originate as raised spots or pimples from which the skin later ruptures and breaks away leaving a frill round the edge and exposing a brown, powdery mass of spore balls beneath. When the spore balls are mostly shed, it is often difficult to distinguish between these scabs and those of Common Scab without microscopic examination. Unlike Common Scab, the organism is favoured by relatively low soil temperatures and high moisture content, and under conditions especially favourable to attack the disease may assume a much more serious canker form, in which the tubers may be malformed and considerable portions of the flesh become involved. Occasionally too, a raised scab may continue to grow and produce a tumour-like outgrowth that may readily be confused with the abnormal growths of Wart Disease (p. 361).

Control Measures. The disease is always worse in rainy seasons and in cold wet soils, and where the land is cropped with potatoes too frequently. A suitable rotation should be adopted and measures taken to improve drainage. Potatoes substantially affected with the disease should not be used for seed, although if infection is only slight, unsprouted seed tubers can be disinfected before planting by steeping them for 3 hours in a solution of formaldehyde containing 1 pint of formalin (38 per cent formaldehyde) in 30 gal. water. Under the Sale of Diseased Plants Orders, 1927–1952, potatoes substantially affected with Powdery Scab may not be sold for planting.

Wart Disease of Potatoes (*Synchytrium endobioticum*). Wart disease was first discovered in this country in 1900 in Cheshire and Lancashire. From these counties it has spread mainly in a northerly and southerly direction and, at present, it is confined to approximately the western and the midland parts of the country.

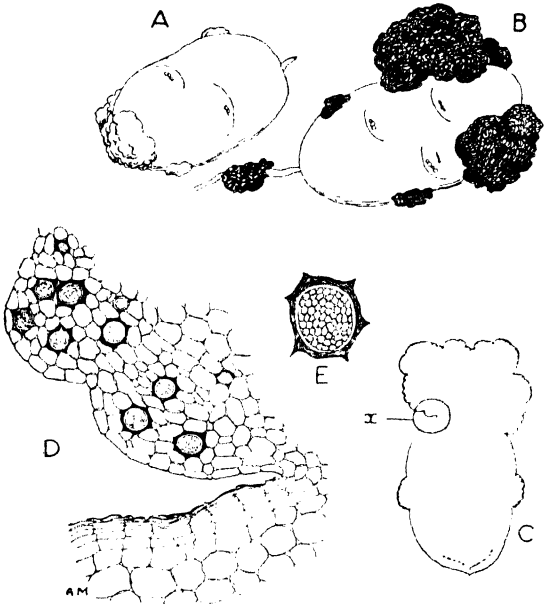


FIG. 61.—WART DISEASE (*Synchytrium endobioticum*).

A, immature warts on tuber.
B, mature warts on tuber.
C, tuber cut lengthwise.
D, section taken at (*x*) showing diseased tissue containing resting sporangia.
E, resting sporangium.

The haulm and foliage of infected plants have a normal appearance and the disease only becomes evident at lifting time, when rough-surfaced, rounded or irregular, tumour-like masses are found on the tubers (Fig. 61). These warts vary in size : on tubers slightly attacked they are little more than small, rough swellings situated invariably on the eyes, but in bad attacks the whole surface of the tuber may be covered with them. In the early stages of growth they are not unlike pieces of the curd of a cauliflower, but as they age their colour changes to a deep brown or black. At this stage they contain many thick-walled, dark-brown sporangia, which are able to survive in the soil for several years. When conditions are suitable, they liberate many motile spores (zoospores), and when these come into contact with the eyes of young tubers infection results. This is followed by the repeated divisions of the neighbouring cells, resulting in the formation of a mass of succulent tissue which in turn is liable to fresh infections. In this large numbers of sporangia, but no signs of hyphæ, develop. These sporangia give rise to motile spores which either re-infect neighbouring cells or tubers near them, or act as gametes and fuse in pairs. The fusion-products, on infecting fresh tissue, give rise to the thick-walled resting sporangia which are set free in the soil when the warts decay.

Control Measures. Fortunately, early in the study of this disease it was found that some varieties, even when grown on heavily contaminated soil, escaped attack, and so a method of checking the spread of this dangerous disease was available and advantage of it was promptly taken. The disease was scheduled under the Destructive Insects and Pests Act. Provision was thus made for compulsory notification of all outbreaks, and with this was coupled the requirement that, on land on which the disease had occurred at any time, planting of potatoes was restricted to approved immune varieties. These and other measures are incorporated in the Wart Disease Order, 1958. Under this Order, moreover, Protected Areas may be defined in which potatoes sold for planting must be certified officially as having been grown on land free from Wart Disease or, alternatively, be uncertified once-grown seed raised within the Area. An area round the Wash is so far the only Area so defined. Among other provisions of the Order are that neither potatoes visibly affected with Wart Disease nor tubers from a crop in which the disease has been found may be sold or offered for sale for planting.

Immune Varieties. The following list gives the names of the more commonly grown *immune* varieties of potato approved by the Ministry of Agriculture and Fisheries for the purpose of this Order.

Early : Arran Pilot, Home Guard, Ulster Chieftain, Ulster Prince, Ulster Premier.
Second Early : Great Scot, Ulster Dale, Craig's Royal, Craig's Alliance.
Early Maincrop : Arran Peak, Majestic, Redskin, Dr. McIntosh, Arran Banner.
Late Maincrop : Dunbar Standard, Kerr's Pink, Ulster Supreme, Arran Consul.

Some of the better-known varieties which are *susceptible* to Wart disease are : Arran Chief, British Queen, Eclipse, Duke of York, Epicure, King Edward, Ninetyfold, Royal Kidney, Sharpe's Express and Up-to-Date. (See also Chapter X).

The problem of finally controlling this disease rests with the plant breeder. The mode of inheritance of immunity and susceptibility has now been investigated and found to take place on simple Mendelian lines, and thus the raising of varieties which the fungus cannot attack is a relatively simple matter. The difficulty, however, is to raise sorts which, whilst possessing immunity, are equal in every respect to the best known. The breeder has to produce large numbers in the hope of finding one or two worthy of general cultivation. All new varieties of potatoes are now submitted for an official test in the early stages of their multiplication, and if a variety does not prove immune from Wart disease there is little prospect of its further propagation or introduction into commerce. The situation is complicated, however, by the presence in other countries of strains of the fungus to which varieties of potatoes resistant to Wart Disease in this country may be susceptible.

Potato Blight (*Phytophthora infestans*). The potato crop, from the time of its introduction in Elizabethan days until about the year 1845, does not appear to have suffered from this well-known disease. In that year it broke out in the Isle of Wight about the middle of August and, in the course of a few weeks, spread throughout the British Isles. Contemporary accounts state that it destroyed between one-quarter and one-half of the crop. In the following year an epidemic started earlier, and was even more destructive. In Ireland it was so severe that nine-tenths of the crop rotted. The Irish famine of 1846 was the direct result of this outbreak.

In recent years the plant breeder has progressed considerably in the production of potato varieties resistant to Blight. Varieties differ in their relative susceptibility, however, and do not always combine both foliage and tuber resistance. King Edward is very susceptible in both tubers and leaves, Majestic is less susceptible in the leaves and still less so in the tubers. Whilst Arran Viking combines considerable foliage resistance and tuber susceptibility, the reverse is largely true for Ulster Beacon. As with other diseases, the plant breeder has to contend with physiologic races of the pathogen, and a number of races of *P. infestans* is now known to exist. Varieties at first resistant may therefore later succumb, and the same variety of potato may also not always respond consistently in different parts of the country, depending upon the geographical distribution of the races.

The first symptom of Blight is the appearance of dark green, water-soaked patches on the tips and margins of the leaves. These increase in size and number from day to day, turning, as they age, to a dark brown colour (Fig. 62). The disease generally spreads with extraordinary rapidity, and it is not unusual for every plant in a field to be infected a fortnight after its first appearance. Later, the tubers may become infected, in which case discoloured and slightly depressed areas appear on the surface. These, when cut across, show rusty-brown stains extending inwards from the skin. Blight does not grow down through the haulm to the tubers ; infection occurs from spores that have been washed down through cracks in the soil. If blighted tubers are clamped they decay rapidly. The rotting is usually the work of other organisms, mainly bacteria, which invade the infected tissue.

When the under surface of an infected leaf is examined more closely, a fine white fringe is seen towards the margin of the infected areas. This consists of branching hyphæ which bear lemon-shaped spores. If these fall on to foliage wetted by rain or dew they give rise to a number of minute motile zoospores, each of which is capable of causing infection. A hypha is sent out from the germinating zoospore and pushes its way through the epidermis or the breathing pores in the leaf. A mycelium then develops within the leaf which discolours and kills the cells. If the spores are washed down to the tubers these also become infected, and their cells are killed and discoloured in the same way.

In some fungi, such as *Pythium* and *Peronospora* which resemble *Phytophthora infestans* very closely, thick-walled resting spores (oospores) capable of surviving through the winter are commonly formed. These germinate in the following spring, or even a year or more later, and thus ensure survival of the fungus, which would otherwise be eliminated by the death of the readily perishable conidia and zoospores. Similar resting spores have been obtained in laboratory cultures of the Blight fungus, but their occurrence has only recently been satisfactorily demonstrated in the field and this only in Mexico. It would seem, therefore, that the fungus is usually perpetuated from year to year solely by mycelium in blighted tubers. These may be left in the field the previous autumn or thrown away when the clamp is opened. The disease may also have its origin in blighted tubers which are inadvertently planted with the healthy ones. The first

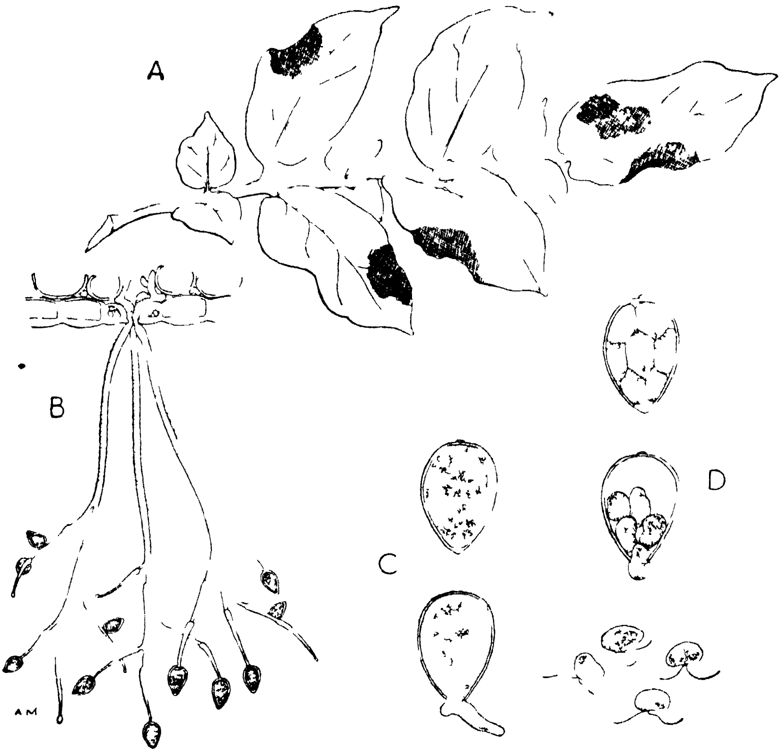


Fig. 62 —Potato Blight (*Phytophthora infestans*).

A, symptoms on leaf
B, branches of fungus emerging from stoma
C, spore germinating directly without producing zoospores
D, sporangium liberating zoospores

outbreaks of Blight are frequently found on " volunteer " plants on or near the site of old potato clamps. Where there is self-sown rubbish of this sort on a farm there is usually disease.

It has long been recognised that weather conditions mainly determine the severity of potato Blight, and that warm, damp, muggy conditions, especially during the latter part of July, favour severe epidemics. The motility of the spores is clearly dependent upon a film of moisture on the foliage and stems and, the more persistent it is, the better are the chances for germination and subsequent infection. Rain, too, splashes the spores further and further afield. Indeed it is now known that from June onwards an outbreak of potato Blight may be forecast with reasonable accuracy if, over a continuous period of 48 hours, the relative humidity of the atmosphere exceeds 75 per cent and the minimum temperature does not fall below 50° F. These infection periods are known as Beaumont periods after the British plant pathologist who defined them. Temperature and humidity, moreover, determine whether the fungus will spread rapidly once it has made an appearance. Hot dry weather makes a severe epidemic improbable and prevents the spread of any infections that have already become established.

Control Measures. As self-sown tubers may be a source not only of blight infection but of virus diseases as well, they should not be left on the fields at harvest time. At the end of harvesting the field should be harrowed and all exposed tubers collected and clamped separately. Blighted tubers should never be left about when the clamp is opened : all " blights " should be carefully sorted, the best of them boiled and used for feeding purposes, and the remainder destroyed. It is not sufficient to cart them away from the site and dump them elsewhere. They should be destroyed so that there is no risk of blighted self-sown plants being produced. Neglected clamp sites are a fertile breeding-ground for disease ; they should be ploughed up as soon as possible and a catch crop taken. Wherever possible seed should be boxed, periodically examined and diseased tubers destroyed.

Spraying. In addition to taking precautions for the reduction of sources of infection, it is necessary in many areas to protect the growing crops. This can be done by spraying the haulm with a suitable fungicide which will kill the spores when they come into contact with it. Two copper fungicides that were at one time used extensively are Bordeaux and Burgundy mixtures. A good Bordeaux mixture for potatoes is one containing 10 lb. of powdered or granular copper sulphate (bluestone) and 12½ lb. of best hydrated lime in 100 gallons of water. The bluestone should be at least 98 per cent pure, and the hydrated lime (bought in paper bags) should be purchased fresh each year. Burgundy mixture is prepared in the same way, but contains 12½ lb. of washing soda instead of the hydrated lime. These mixtures have now largely been replaced by proprietary fungicidal preparations sold as powders or pastes for ready mixing with water. Some are based on copper but others on the more recently developed organic fungicides such as the dithiocarbamates which, although they are less persistent, are less liable to scorch or check the growth of the potato foliage. In recent years low-volume spraying against potato Blight, either with ground machines or from the air, has been practised successfully in some parts of the country. Only about 20 gallons or less of spray liquid are used per acre. In south and south-west England, in Wales, and other districts where the disease appears first and is most severe, spraying should be regarded as a routine summer operation. In these districts, however, the crop unit may be very small indeed, and measures more in keeping with the farm economy would be timely planting, good earthing up, and delayed lifting until after the haulm is completely dead.

The date at which the crop should be sprayed varies with the season and the district, but it should be done before, or as soon as, Blight spots are seen on the foliage. In this country, Blight warnings based on the widespread occurrence of Beaumont periods are reported in the Press and by sound radio and television, together with records of first outbreaks. The information is useful even if it may not immediately be applicable locally, for it calls attention to the advisability of having everything in readiness. For maincrop varieties two applications of fungicide are required, one before the plants meet in the rows and the other about three weeks later ; in seasons when Blight is severe a third may be necessary. Earlies usually do not require spraying. In some districts, where there is difficulty in carting water, dusting with proprietary copper powders is practised. This is a convenient and speedy method, but it is not as effective as spraying. Four, five, or more applications at fortnightly intervals may be necessary, beginning before the plants are earthed up.

Fine weather is essential for spraying operations, and no opportunities should be missed of carrying out the work on a still, windless day, when the spray mist will settle down uniformly. Once the coating has dried thoroughly on the foliage it will adhere for a long time, but if rain falls before this happens much of it will be washed away. If dusting is practised it should be carried out early in the morning whilst dew is still on the leaves. Spraying or dusting with copper fungicides should not be done in the immediate vicinity of large industrial areas, as injury to the foliage may result owing to an interaction of the spray and acid fumes in the atmosphere.

The result of protecting the crop from infection is that the haulm continues to grow for a longer period than it otherwise would and, as a consequence, the crop from a field which has been thoroughly sprayed is larger than that from a field in which the foliage has been prematurely killed by Blight. Many farmers, however, do not carry out this spraying or dusting operation themselves, but engage the services of spraying contractors.

Protection of the Tubers. The better the earthing-up of the rows, the less chance Blight spores have of reaching the tubers during the growing season. A great deal of tuber infection may take place at lifting time, however, during the period that the potatoes lie exposed on top of the soil. If digging can be delayed until the tops have been quite dead for at least a fortnight, the risk of this happening is much reduced, as most of the spores will have perished. If the tops remain green very late, however, and Blight is present, they should be "burned off" about 10 days before lifting. One of the most efficient substances for potato haulm destruction is sulphuric acid, at the rate of 12–15 gallons B.O.V. in 85 gallons of water per acre, and this is still widely used but requires acid-resistant machines and considerable care in its use. Newer chemicals, more convenient to use and non-poisonous, although as yet expensive, are now being developed as total weedkillers, and hold promise as efficient but safe haulm destroyers. Of these, diquat has been found to be very effective. Mechanical methods of destroying potato haulm have been introduced in recent years, and these have also been shown to reduce tuber infection at lifting. An associated and very valuable advantage of burning off potato haulm is the destruction of weeds, which greatly facilitates the digging and lifting operations.

Two other Phycomycetes, related to the potato Blight fungus and belonging to the sub-class Peronosporales are *Peronospora schachtii* causing Downy Mildew of sugar beet ; and *Peronospora parasitica*, various physiologic strains of which are found causing Downy Mildew on wild and cultivated members of the Cruciferae, including Brassicas and wallflowers.

Downy Mildew of Sugar Beet (*Peronospora schachtii*). This fungus attacks sugar beet, beetroot and mangels and can be serious on sugar beet crops in the midland and eastern counties of England, especially where seed and root crops are grown in close proximity to one another. Seedlings are occasionally attacked, but symptoms are more often seen after singling, when the growing point and central rosette of leaves may become affected. The young leaves become pale-green, thickened, curled and brittle, and on the under surface the fungus may be seen as a lilac-grey, downy growth which later changes to buff-grey. Spore production is encouraged by mild weather and high humidity and, under conditions favourable to infection, the older leaves too may be attacked, but mostly towards the basal parts of the leaf blade. With the death of the heart leaves, confusion can often arise through the similarity of symptoms with those of Heart Rot resulting from boron deficiency. On the seed crop the symptoms at first resemble those on the root crop, and many of the stecklings may be killed. Infected plants, moreover, are more readily killed by frost. Infected plants that survive are stunted, with suppressed axillary floral shoots, and later infections, too, cause damage to the seed-bearing stalks with resultant reduction in yield. Oospores may be formed in the leaves and flower parts, and it is thought that the disease might be seed-borne, although there is little indication of this being a serious factor in this country. The greater danger lies in the continuity throughout the year of sources of infection from air-borne conidia. This occurs where seed crops and root crops are grown in close proximity.

Control Measures. Stecklings raised for the seed crop should be grown in isolation and planted as far removed as possible from root crops or other sources of infection. Individual plants found later to be affected should be lifted immediately and buried *in situ*, to minimise dissemination of spores through the crop. Conversely, root crops should not be sown in the vicinity of crops being raised for seed. Control by the application of fungicides is scarcely practical or effective on root crops, although some benefit might be derived from protecting the more restricted steckling beds by the periodic application of a copper fungicide in the early stages of growth. Spraying, however, should be discontinued when there is the likelihood of frost occurring.

Downy Mildew of Brassicae (*Peronospora parasitica*). Many cruciferous plants are attacked, including most of the cultivated species. Infection is commonly found on the older leaves of kale, cabbage, brussels sprouts and cauliflower, where it is usually of little consequence. The fungus occurs as a thin, greyish-white, downy growth in scattered, angular patches bounded by the veins on the underside of the leaves. The corresponding areas on the upper surface are often pale and chlorotic.

Control Measures. There are no practical measures that can be adopted for controlling the disease in field crops, and its incidence there is not usually of sufficient economic significance to warrant any special concern. The disease is favoured by high humidity, however, and very severe infection can arise in seedlings such as cauliflowers growing under glass, especially when the seedlings are dry at the roots and atmospheric humidity is high. In these circumstances abundant ventilation should be given, and it is helpful if the seedlings are not too crowded. Protective spraying at regular intervals with zineb or a fungicide containing copper will sometimes hold the disease in check but, to be effective, applications must commence before the disease becomes established. If copper is used, care should be taken to avoid it reaching the roots as in some circumstances it may cause damage.

DISEASES CAUSED BY ASCOMYCETES

The chief characteristic of the Ascomycetes is the formation at some stage in the life-cycle of an *ascus* (a sac-like cell inside which a definite number of spores, usually eight, is produced). This class, which includes many important parasites, is widely distributed, and some of the more important types are now described.

An important family is the *Erysiphaceæ*, for its members are responsible for the Powdery Mildews which occur on a wide range of host plants. These include clovers, swedes, apples, roses, gooseberries, hops, cereals and grasses.

The Powdery Mildews. The mycelium is superficial and spreads over the foliage, the young shoots, and occasionally the young fruits, in the form of a delicate cobweb-like layer. This is white in colour at first, but becomes grey or brown as growth proceeds. The hyphæ are fixed to the host plant by haustoria driven through the cuticle of the epidermal cells, and it is by means of these suckers that the fungus absorbs food. Though the invasion of the host by the parasite is extremely slight, the infected plants often die prematurely, and consequently these mildews are responsible for much damage. Later, from the superficial weft of mycelium, upright branches arise, and transverse walls form to divide them up into chains of elliptical conidia, which are abstricted one after another. At this stage the surface has a characteristic mealy appearance, but after a time the mycelium becomes denser and often changes in colour. In the thickened weft small yellow, and finally brown or black, dots develop. These are the cleistocarps. They are completely closed, globular structures containing one or more asci, within each of which are eight ascospores. The wall of the cleistocarp is formed of a layer of dark, close-fitting cells, from some of which simple or branched appendages grow. The various genera comprising this family are identified by the shape of these appendages and, also, by the number of asci within the cleistocarps ; it is almost impossible to distinguish them by the conidial chains, which are very similar to one another in general appearance.

The spread of powdery mildews during the growing season of their hosts is brought about by conidia, or " summer spores " as they are sometimes called. These are readily caught up in air currents and are scattered far and wide. When one of them reaches the surface of a leaf or shoot of a suitable host plant it anchors itself by the formation of a sucker-like disc (appressorium) ; a hypha is then formed from which an haustorium is soon driven into an epidermal cell. It is the ascospores within the cleistocarps, however, which provide the over-wintering stage of the fungus. They are set free explosively in the spring and early summer, and on germination give rise to mycelium similar to that developed from a germinating conidium. The life history of *Erysiphe graminis*, which is responsible for the widely distributed Powdery Mildew of cereals and grasses, is typical of most powdery mildews.

Powdery Mildew of Cereals (*Erysiphe graminis*). This fungus (Fig. 63A) affects wheat, barley, oats, rye and the common grasses, and it exists in a number of specialised strains, each usually specific to its own host. The cereals vary in their susceptibility to mildew, but there are no varieties commonly grown in Britain which are immune. The disease is most noticeable in crops which have been thickly seeded and liberally manured ; it is also often severe on late-sown spring corn, especially when this has been checked by drought. Lodging of cereals is sometimes attributed to mildew, but there is no evidence for this, although in some seasons it can reduce considerably the yield and quality of grain. Although mildew can be controlled in experimental plots by successive applications of lime sulphur, this is not economically practical in the field. Cereal varieties vary in their susceptibility to mildew, however, and control in the future could be in the further development of resistant varieties. It is advisable to avoid thick sowing and over-manuring with nitrogen

An important sub-class of the Ascomycetes is the **Pyrenomycetes,** or Flask Fungi, examples of which are the fungi causing the well-known Ergot of cereals and grasses (see Fig. 63C), and Choke of cocksfoot and other grasses.

Ergot of Cereals and Grasses (*Claviceps purpurea*). The hard, purplish-black, horn-like ergots of *Claviceps purpurea* are commonly seen protruding from the florets of grasses, especially ryegrass. The fungus exists in a number of physiologic strains affecting cereals and a wide range of grasses. Of the cereals, rye is most susceptible and wheat and barley much less so. The now rarely seen Rivet, and varieties derived from Rivet, are the varieties of wheat more commonly affected. Oats are seldom infected, and only once has it been recorded on oats in this country.

Only the inflorescence is affected, and infection by means of ascospores takes place through the open florets. The fungus invades the ovaries to convert them into a white, compact mass of mycelium; the early stage in the production of the sclerotia or ergots. On the tip of the developing ergot, conidia are abstricted and a sugary fluid or " honey-dew " is secreted. This is the sphacelia stage, when rapid dissemination of the fungus takes place from flower to flower by means of insects or rain splashes. The ergots gradually lengthen, and become hard and black, so that by harvest time they are mature. They then fall to the ground or they may be threshed out and sown with the grain.

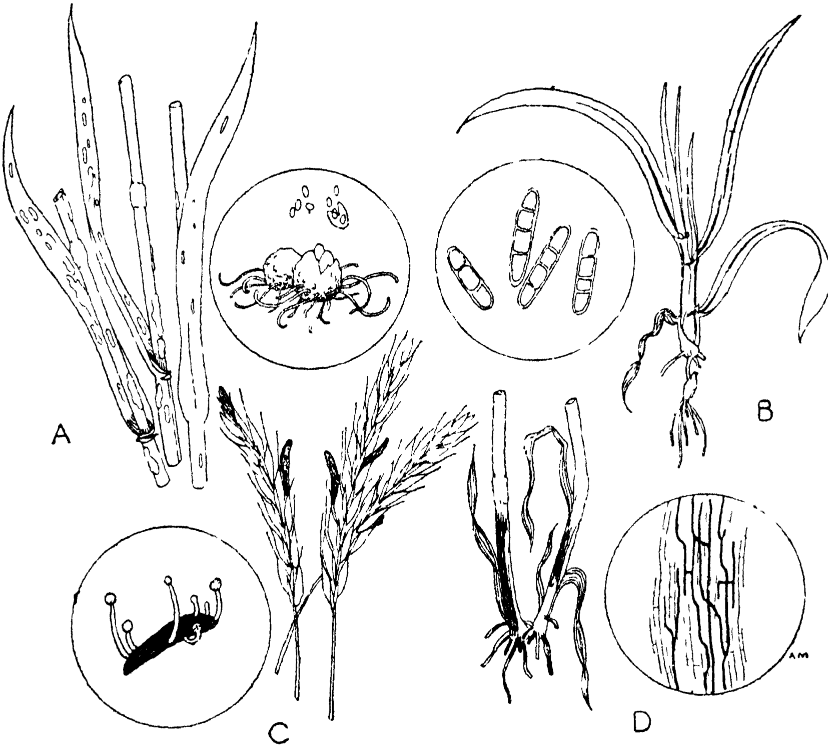


FIG. 63.—FOUR DISEASES CAUSED BY ASCOMYCETES.

A. Powdery Mildew (*Erysiphe graminis*). *Inset:* cleistocarps, asci and ascospores
B, Barley Leaf Stripe (*Pyrenophora graminea*). *Inset:* conidia.
C, Ergot (*Claviceps purpurea*). *Inset:* ergot germinating
D, Take-all and Whiteheads (*Ophiobolus graminis*). *Inset:* Runner hyphæ on rootlet.

If not buried too deeply in soil, the ergots germinate in early summer to give rise to small, club-shaped stalks that swell at the tips to produce stromata in which are embedded numerous flask-shaped perithecia. It is within these perithecia that the asci, each containing eight thread-like ascospores, are produced, at about the time of flowering of the host plant. The ascospores are then forcibly ejected and carried by the wind to cause fresh infections in newly opened florets.

The ergots of *Claviceps purpurea* have long been known for the toxic and medicinal properties of the alkaloids that they contain ; gangrenous and nervous disorders in both man and animals can arise if food containing quantities of ergot as a contaminant are consumed. The alkaloidal content of ergots, however, can vary very widely. In his book " Ergot and Ergotism ", George Barger (1931), describes very fully the symptoms and history of human ergotism.

Control Measures. Rotation of crops, deep ploughing to bury fallen ergots, and the use of clean seed will remove sources of infection. Ergots buried deeply in the soil do not germinate, and they are relatively short-lived. Grasses in pastures, especially ryegrass, are sometimes heavily infested, but this should not occur if the grasses are prevented from flowering by close grazing or mechanical topping. With contaminated grain samples, much of the ergot is removed in the cleaning operations, but seed can also be freed from contamination by pre-soaking in water and floating off the ergots in a saturated salt solution.

Choke of Cocksfoot (*Epichloe typhina*). Many kinds of hedgerow and pasture grasses besides cocksfoot are affected. The disease is conspicuous because of the bright-yellow stromata of the fungus, *Epichloe typhina*, which sheathes and suppresses the flowering tillers. The mycelium of the fungus is systemic within the tissues, and perennates in the rhizomes and vegetative organs of the host, only appearing on the surface of the plant during the summer months. In early spring the mycelium emerges as a weft encompassing the youngest leaf of the developing flowering tiller. As the mycelial growth increases in density to form a stroma, the inflorescence becomes trapped and degenerates, a feature from which the name Choke has been derived. At this stage the stromata are white, and from them are abstricted numerous conidia. As the season progresses the colour of the stroma changes to bright yellow, and immersed in it are numerous perithecia within which are produced asci, each containing eight thread-like ascospores. The ascospores when mature are forcibly discharged into the air and carried away by wind. The rôle of conidia and ascospores is obscure, and little is known about the control of the disease. Fortunately the disease appears to be of little consequence in pastures, and its economic importance lies more in the damage sometimes caused to crops raised for seed production and in the shortening of their period of productivity.

Other troublesome fungi in this sub-class of the Ascomycetes are those responsible for Apple and Pear Canker (*Nectria galligena*), Apple Scab (*Venturia inaequalis*), Pear Scab (*V. pirina*), and certain species of *Pyrenophora* (conidial stage = *Helminthosporium*) which attack barley and oats. For example, Leaf Stripe of Barley (*Pyrenophora graminea*), and Leaf Spot of Oats (*P. avenæ*) are seed-borne parasites that are often responsible for much damage. A very similar disease, Net Blotch of Barley (*P. teres*), is also widely distributed, but it is not so important. The causal agents of these three diseases are often referred to as *Helminthosporium gramineum*, *H. avenæ* and *H. teres*, since their perfect stage is rare and has not been definitely recorded in Britain.

Leaf Stripe of Barley (*Pyrenophora graminea*). The characteristic symptoms of Leaf Stripe are long and narrow brown stripes on the leaves. The fungus causing the disease is present in a dormant state on the surface of the grain or in the seed coat, but it cannot be detected by the unaided eye. When infected seed is sown the fungus resumes growth and attacks the young shoot as it emerges from the seed. The course of the disease is usually progressive ; the first leaf becomes infected, then the second, the third, and so on, and finally the ear. This may be so severely affected that a condition of " blindness " results, in which the grains fail to develop normally. When adverse weather conditions prevail (low soil temperatures favour the disease) the young shoots may be killed before they pierce through the soil, and affected seedlings that do emerge may be so weakened that they eventually succumb. Leaf Stripe, therefore, may lead to thin stands, reduced yields, and grain of low quality. In the past this disease caused much loss, but it can be prevented by treating the seed with an approved organo-mercury seed dressing.

The related disease, Net Blotch of Barley (*Pyrenophora teres*), is controlled in the same way.

Leaf Spot of Oats (*Pyrenophora avenæ*). Leaf Spot of Oats is very similar to the related Leaf Stripe disease of barley. The fungus is carried on the surface of the grain or in the husks and seed coat, and the young shoot is infected as it emerges from the seed. In cold wet weather many of the infected seedlings die ; others are severely crippled, and their leaves bear reddish-brown streaks. For a period after tillering the symptoms of the disease are not very noticeable, but later brown spots appear on the maturing upper leaves, and it is from these that spores are spread which later infect the grain. The disease can be prevented by treating the seed with an approved organo-mercury seed dressing. Most reputable seed merchants now treat cereal seed as a routine measure so that Leaf Stripe and Leaf Spot are much less common than in the past.

Take-all (*Ophiobolus graminis*). Take-all and Whiteheads of wheat barley and oats is another important disease, for it often reduces the yield considerably, especially when cereal crops are grown too frequently on the same field. The disease is due to a soil-inhabiting fungus (*Ophiobolus graminis*) that infects the roots and the base of the stem (Fig. 63D). There are at least two strains of the fungus : an oat strain that can affect all three cereals and is confined mainly to the wetter parts of the country, and a wheat and barley strain that does not affect oats. Affected plants ripen prematurely and produce bleached ears containing little or no grain, and it is this feature that has led to the use of the term " Whiteheads ". Somewhat similar symptoms, however, may arise from other causes, but when the condition is due to *Ophiobolus* there is a black discoloration at the base of the stem and the roots are grey and rotten. As crops other than cereals and grasses are not attacked, the fungus can be starved from the soil by avoiding susceptible crops and by keeping the land free from weed grasses. When Whiteheads has appeared in a wheat or barley crop it should not be followed by either of these crops, but a non-cereal, such as roots, should be grown or, in the drier parts of the country where the oat strain rarely occurs, oats can be taken as a cereal crop. It should be noted, however, that as the fungus may attack grasses, temporary leys containing these will not starve the fungus from the soil, although the level of infection may nevertheless be reduced substantially.

Where it is not possible to avoid successive susceptible crops, the effect of the disease can be minimised by early ploughing in of infected stubble, spring sowing, reduced rates of seeding and the maintenance of a high level of fertility.

Another important sub-class of the Ascomycetes are the **Discomycetes** or Cup Fungi, characterised by asci borne on open, frequently cup-shaped, fruiting bodies called *apothecia*. It includes the important genus *Sclerotinia*, members of which give rise to many destructive diseases including Clover Rot, and Brown Rot of apples and plums.

Clover Rot (*Sclerotinia trifoliorum*). When red clover is grown too frequently on the same land a condition known as " clover sickness " often appears. This is sometimes due to the presence in the soil of a parasitic eelworm, but more often it is caused by the Clover Rot fungus. The disease is likely to be most severe during a mild winter following a wet autumn, but when dry frosty conditions prevail the rot is checked, and spells of such weather may lead to a partial crop recovery.

The first symptoms appear in the autumn months on plants arising from sowings made in the previous spring. The early stages of the disease, characterised by a " peppering " of the foliage with small brown spots, are not generally noticed, and it is only in the late winter and early spring, when widening patches of dead plants are seen, that the extent of the trouble is realised. On the upper part of the root and the neck of such plants black bodies develop which vary in size from a pin's head to a small pea (Fig. 64). These are hard compact masses of mycelium known as sclerotia, and, as they are able to withstand desiccation and freezing, they function as a resting stage for the fungus. It is these bodies which contaminate the soil and are responsible for subsequent attacks of Clover Rot. They can also sometimes be carried over as contaminants in seed and thus play a part in spreading the disease. They remain dormant in the soil during the summer, but, in the early autumn, those within an inch or so of the surface germinate and produce flesh-coloured, saucer-shaped, stalked bodies. These are known as apothecia and they bear asci which discharge ascospores. When these come into contact with susceptible plants, and the surfaces of the leaves are wet, the spores immediately germinate and infection results. Sclerotia more deeply buried may decay, but some remain in a living state for several years. When cultivations bring them near the surface, however, they too may germinate.

The Clover Rot fungus only attacks clover and related plants, and they vary in their susceptibility to the disease. Common or broad red clover is very susceptible, but late-flowering red clover (single-cut cow grass) may also be severely attacked. Trefoil, although often affected, withstands the disease better. Alsike and white clover are less susceptible. In their first year sainfoin and lucerne may be attacked, but failures seldom occur and they show increasing resistance after one season's growth. Vetches, peas and spring-sown field beans appear to escape the disease, but this is not so with winter-sown beans for they are sometimes severely affected with Bean Rot, a disease caused by a varietal form of the same fungus.

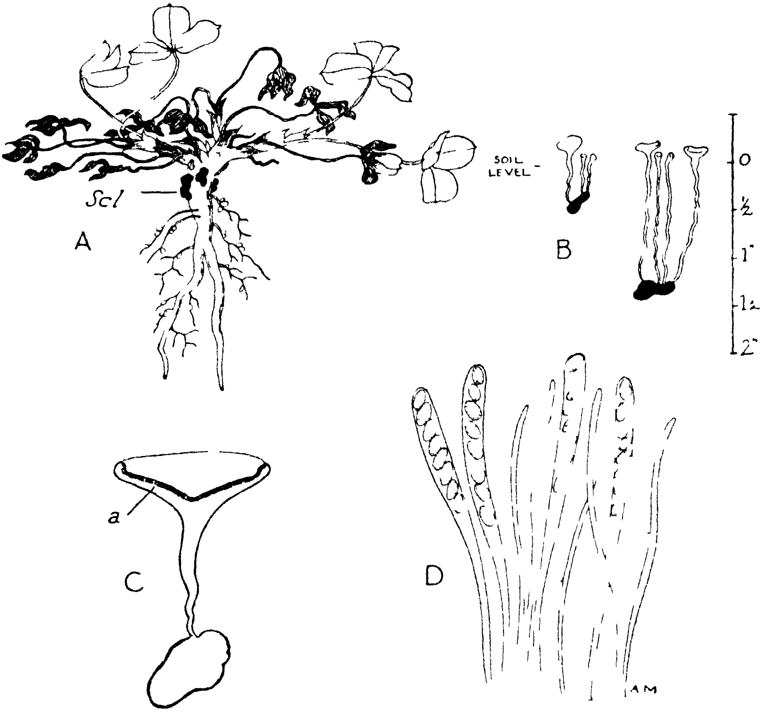


FIG. 64—CLOVER ROT (*Sclerotinia trifoliorum*).

A, affected plant with sclerotia (*Scl*) on root
B, germinating sclerotia
C, sclerotium and apothecium cut lengthwise showing position of asci (*a*).
D, asci containing ascospores

Control Measures. In fields where Clover and Bean Rot has occurred the only method of avoiding further losses is to starve the fungus from the soil by growing only those crops which are resistant to the disease or less susceptible to it. An interval of eight years should pass before common red clover and late-flowering red clover are taken again. During this period sainfoin or lucerne can be sown if the soil conditions are suitable, or alsike or white clover may be substituted, either alone or with Italian ryegrass. As peas and vetches escape the disease they too may be grown, but it is unwise to sow winter beans.

DISEASES CAUSED BY BASIDIOMYCETES

The Basidiomycetes include such well-known saprophytes as mushrooms, toadstools and puff-balls. At some stage in the life-cycle a more or less club-shaped body called a *basidium* is formed, and this normally bears four spores. For example, the gills of mushrooms bear basidia, and these also line the tubes of the large fruiting bodies of the bracket-shaped fungi that cause disease in forest trees and hedgerow timber. The basidia may be septate as in the Sub-class Heterobasidiomycetes, or without septa as in the Sub-class Homobasidiomycetes. Three Orders contained within the Sub-class Heterobasidiomycetes are the Tremellales, the Uredinales or Rust fungi, and the Ustilaginales or Smut fungi, and one of the Orders within the Heterobasidiomycetes is the Agaricales. Some typical examples are now described.

The majority of the members of the Order Tremellales are saprophytes, although some are parasitic on mosses, and the Order includes the Genus *Helicobasidium*, of which the species *H. purpurea* is parasitic, and produces Violet Root Rot in a wide range of cultivated crops.

Violet Root Rot (*Helicobasidium purpureum*). Of the cultivated crops, sugar-beet, carrots and potatoes can at times be affected seriously and the disease may especially be troublesome in asparagus beds if the seedling plants have been raised on infested land. Other susceptible crops include lucerne, clover, beans, swedes and celery, and the fungus has been found on such diverse hosts as cucumber and carnation, besides a wide variety of weeds. The fungus is soil-inhabiting and is more common in light, alkaline soils. It spreads slowly, and usually occurs in sharply-defined patches in the wetter parts of the field to produce stunted, unthrifty-looking plants. Soil tends to cling to such infected plants on lifting, but when washed off a characteristic violet-coloured weft enveloping the affected parts can be seen. On severely attacked plants the below-ground parts are pervaded by a brown rot, often followed by secondary invaders to cause a slimy bacterial breakdown.

Just visible to the unaided eye, but clearly distinguishable with a hand lens, numerous dark-coloured raised spots can be seen distributed along the strands forming the purple web of mycelium. These infection cushions, or " corps miliaires " as they are sometimes called, enable the fungus to penetrate and parasitise the host tissue. Besides these, the mycelium may produce small rounded, reddish-violet sclerotia up to a quarter of an inch in length. These resting bodies are shed into the soil when the roots rot and are a means of ensuring survival of the fungus in the absence of a host plant.

The spring stage in which the basidia are formed is rarely observed, but it may be seen in early summer as a white " bloom " on a felt of purple mycelium on stems of affected plants just above ground level and spreading over the surface of adjacent soil.

Control Measures. Although light, dry soil conditions are said to favour attack by the fungus, survival of the mycelium and sclerotia is greatest under wet conditions. Land should be kept in good heart, at a high level of fertility and well-drained, for under these conditions severe attacks are rare. Cereals are not known to carry infection, and their place in the rotation provides a suitable break from susceptible crops, but groundkeepers and weed hosts must be kept under control. As far as possible, infected material should not be ploughed back into the land.

The Uredinales or Rusts. All the members of this large and complicated Order are obligate parasites which attack a wide range of host plants, including some of the most important crops.

The life history of the rusts differs markedly from that of all other kinds of fungi for, in those in which the cycle is complete, there are three well-defined stages, the *uredospore*, the *teleutospore* and the *æcidial* (Fig. 65). The uredo stage consists of thin-walled, one-celled uredospores, brown or rusty-red in colour. They germinate rapidly when conditions are favourable and quickly cause infection. It is this stage which serves for the rapid dispersal of the fungus. It is followed by the teleuto stage, consisting of thick-walled, dark-coloured teleutospores which in some genera are single celled, in others two, three or many celled. These usually function as resting spores. On germination they give rise to a basidium with cross walls, each section of which produces a single basidiospore on a slender stalk. These spores infect their appropriate host, and this may be one of the same kind as that which produced the teleutospore or it may be totally different. For example, the teleutospores of Plum Rust lead to the infection of anemones, and the teleutospores of Black Rust of wheat to a disease of the common barberry. Rusts requiring two different kinds of host plants to complete their life-cycle are described as *heterœcious*, whilst those for which a single kind is sufficient are *autœcious*. There is no obvious relationship between the hosts required by heterœcious rusts, and the discovery of their life histories has been effected only by lucky observations or by lengthy infection experiments on every possible alternate host.

The mycelium arising from infection by basidiospores produces the æcidial stage. Each æcidium, when mature, is a white-frilled, cup-like structure containing chains of spores which, seen in the mass, are a bright orange colour. The spores are thin walled, single celled and capable of immediate germination. The mycelium to which they give rise quickly produces a crop of uredospores. In the autœcious species this will be on the same host, but in the heterœcious rusts on the alternate host. Thus, the æcidiospores produced on garden anemones give rise directly to Plum Rust, and those produced on the common barberry to Black Rust of wheat. The lack of the requisite host breaks the life-cycle of the rust, and consequently it is sometimes possible to prevent the spread of a particular rust by destroying the alternate host.

Accompanying the æcidia are minute flask-shaped structures or spermogonia, from which large numbers of spermatia are exuded in a drop of sweet-smelling " nectar ". The spermatia play an important part in the development of the rusts. The mycelium arising

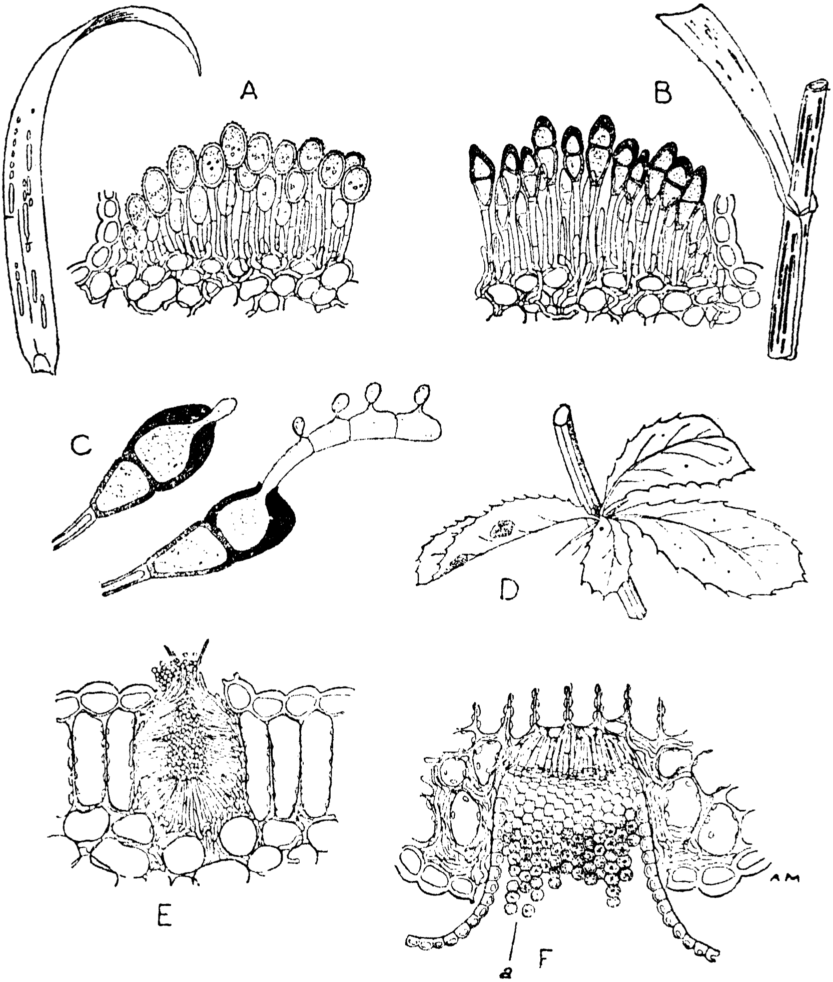


FIG. 65.—BLACK RUST (*Puccinia graminis*).

A, uredospore pustules on leaf, and single pustule enlarged.
B, teleutospore pustules on stem, and single pustule enlarged.
C, germinating teleutospores.
D, cluster cups on under surface of Barberry leaves.
E, section of spermogonium.
F, section of æcidium showing æcidiospores (*a*).

from infection by a single basidiospore forms perfect spermogonia and the rudiments of æcidia. But the complete development of the æcidia is dependent on the mingling of nectar, containing spermatia, from spermogonia resulting from more than one infection. This is generally effected by insects. There are thus + and —, or male and female, strains in the rusts. Whilst all these spore stages occur in the majority of the rust species, the life-cycle of some has been simplified by the omission of one or another stage. The common rust of hollyhocks and mallows (*Puccinia malvacearum*) provides an extreme example, for the teleutospore, with its accompanying basidium stage, is the only one produced.

Black Rust of Wheat (*Puccinia graminis*). The rust fungi attacking the cereals give rise to some of the most important diseases with which farmers have to contend, but fortunately, in Great Britain, these are not too serious. Elsewhere, however, the losses which they cause assume fabulous proportions. Thus, the Canadian wheat crop in 1916 was only some 27,500,000 quarters as compared with the previous year's crop of 47,000,000 quarters, the difference being almost entirely due to an intense outbreak of Black Rust (*Puccinia graminis*).

Although Black Rust attacks wheat, oats, barley and rye, as well as various grasses, it cannot spread indiscriminately from one cereal to another, or from the grasses to the cereals. It exists in a number of varieties, each of which is more or less rigidly confined to its own special host or group of host plants. Thus, although it is not possible, even by the aid of a microscope, to distinguish Black Rust on wheat from Black Rust on oats, or rye, the fungus on wheat cannot readily attack these other hosts, and vice versa.

Physiologic Races. Indeed, it is even more specialised than this, for within a given variety of Black Rust, such as *Puccinia graminis tritici* (the variety attacking wheat), there is a large number of physiologic races. When two similar series of wheat varieties are inoculated with uredospores of *P. graminis tritici* obtained from two distinct sources, the results are often different. Thus the rust from one source may fail to infect some of the varieties of wheat, whilst that from the second source attacks them readily, or vice versa. Or again, the rust from one source may produce a heavy infection on one wheat and that from the other only a slight one. Many thousands of infection experiments, carried out on a special standard series of wheats, have fully established this fact and led to the recognition of more than 200 physiologic races. The demonstration of the complex nature of Black Rust has lead to an explanation of the puzzling phenomenon that wheats immune to its attacks in one country are often susceptible when grown in others. Their power of resistance has not broken down under the new conditions, as was often assumed, but they have been exposed and have succumbed to the attacks of different races of the parasite.

Control Measures. The control of Black Rust has proved to be difficult. The extermination of the alternate host, the barberry, was recommended as a means of control a century and a half before the life-cycle of the fungus was known. It was enforced by legislation as early as 1756 in Massachusetts. In some of the American states its destruction has been carried out on a large scale for a long period. Unfortunately, the rust can survive without completing its life-cycle on the barberry provided that plants are available for the production of uredospores, or as long as these are not killed by adverse weather conditions. This occurs in Australia, where the barberry is unknown, and in the southern United States. In the Canadian prairies barberries are also absent, and in these areas rust starts from wind-borne uredospores from infected crops in the United States. In England Ogilvie and Thorpe have shown that the Barberry plays little part in the initiation of epidemics and that the severe attacks that do occur in some seasons, mostly in the south-west and along the south coast, follow widespread and early infections by uredospores carried northwards from North Africa and Spain in high-altitude air streams.

The possibility of raising wheats which are resistant to the attacks of Black Rust has been patiently investigated for many years. A pronounced immunity has been found amongst the members of two groups, namely, the macaroni wheats (*Triticum durum*) and the emmer wheats (*Triticum dicoccum*). Certain varieties of these have been found to come practically unscathed through the severest of epidemics. After many attempts their rust-resisting power has now been built by plant breeders into typical bread wheats, and the foundations have been laid for securing new types suitable for cultivation under various conditions. Once their cultivation can become general the menace of Black Rust will largely disappear.

Black Rust is of much more importance abroad than it is in this country, although many years ago it was prevalent here. It can still be found on late-sown crops, but the attack usually starts so late in the season that little harm results. Koga II is a variety rather liable to attack by Black Rust.

Yellow Rust (*Puccinia glumarum*) is the common wheat rust in England, and it can readily be distinguished from other cereal rusts by the deep cadmium yellow colour of the uredospore pustules which are closely crowded together in parallel lines. The severity of the disease varies greatly from year to year, but usually it does not cause very appreciable losses. Weather and soil conditions play an important part in determining the intensity of Yellow Rust attacks. Cool moist weather favours its development, but in hot dry seasons it makes little progress. It is most severe on rich, well-farmed land, especially when nitrogenous manures have been used in an attempt to secure a heavy crop.

There are two stages, the uredospore and the teleutospore, but, as far as is known, no æcidial stage. The starting-point of epidemics in this country is provided by the over-wintering of the uredospores. These remain viable for a long period under normal climatic conditions, though a spell of hot dry weather in the early autumn may bring about their wholesale destruction. Further, an almost continuous supply of host plants is available owing to the necessity for sowing wheat during the autumn months. Yellow Rust, however, makes little progress during the cold weather, and it is only exceptionally that heavy infection occurs by the end of March. More generally the epidemic starts to become severe towards the end of May, the uredospore stage continuing to develop as long as any green foliage is available.

Control Measures. The only method of avoiding losses through the attacks of Yellow Rust is by growing varieties which are not markedly susceptible to its attacks. The common varieties vary in their resistance to rust, but it does not necessarily follow that because a variety is not attacked that it is immune to disease. Yellow Rust also exists in specialised races, and these may not always be uniformly distributed. It is only by observations made over a number of years that the relative resistance of varieties to Rust can be assessed. Atle and Koga II are among the more resistant varieties in cultivation at present, but if the climatic conditions are favourable for the rust, infection can be induced by generous applications of nitrogenous manures. Cappelle Desprez, Flamingo and Jufy I on the other hand are much more susceptible. Between these extremes, and differing in their degree of susceptibility, are the remainder of the commonly grown varieties. The losses caused by the rust diseases in this country are seldom serious, and in normal circumstances, a wheat variety should be chosen primarily to suit the soil texture and the standards of fertility.

Other Rusts. There is a third Rust which occurs on wheat in Britain, Brown Rust (*Puccinia triticina*). Although the scattered brown pustules of the uredospore stage are often very abundant on the foliage in June and July, the losses caused are relatively slight. In Britain few teleutospores are formed, and the cluster cup stage has not yet been discovered, but in the United States of America and Russia it has been found on certain species of *Thalictrum.* Other rusts of cereals occurring in Britain are Brown Rust of Barley (*Puccinia anomala*), Crown Rust of Oats (*Puccinia coronata*), and Brown Rust of Rye (*Puccinia dispersa*). Fortunately, in normal seasons, the injury caused is relatively slight and control measures are not necessary.

The Ustilaginales or Smuts. The chief species of agricultural importance form their spores (brand spores) in the ovaries of the various cereals, and give rise to two types of smut diseases—" covered " and " loose ". Distinct species occur on wheat, oats and barley, and there is evidence that, as in the rusts, the species consist of physiologic races. In covered smuts the skin of the diseased grain remains more or less intact and keeps the spores enclosed in a compact form, but in loose smuts the skin does not persist very long and the spores are blown away leaving a bare stalk.

In some smuts the brand spores bring about infection directly, but in others they give rise on germination to a short basidium (promycelium) from which basidiospores (sporidia) are abstricted (see Fig. 66). These often fuse together in pairs. A hypha then develops which may serve to bring about infection or give rise to a spore-bearing mycelium.

Most of the smuts have singularly little effect on the general health of their hosts which, though infected in the seedling stage, show no symptoms of disease until the grain is formed. The losses they cause, however, are of world-wide importance, and a brief account of the more important diseases, and the methods of preventing them, is now given.

Covered Smut of Wheat (*Tilletia caries*). The presence of this disease, other names for which are " bunt " or " stinking smut ",

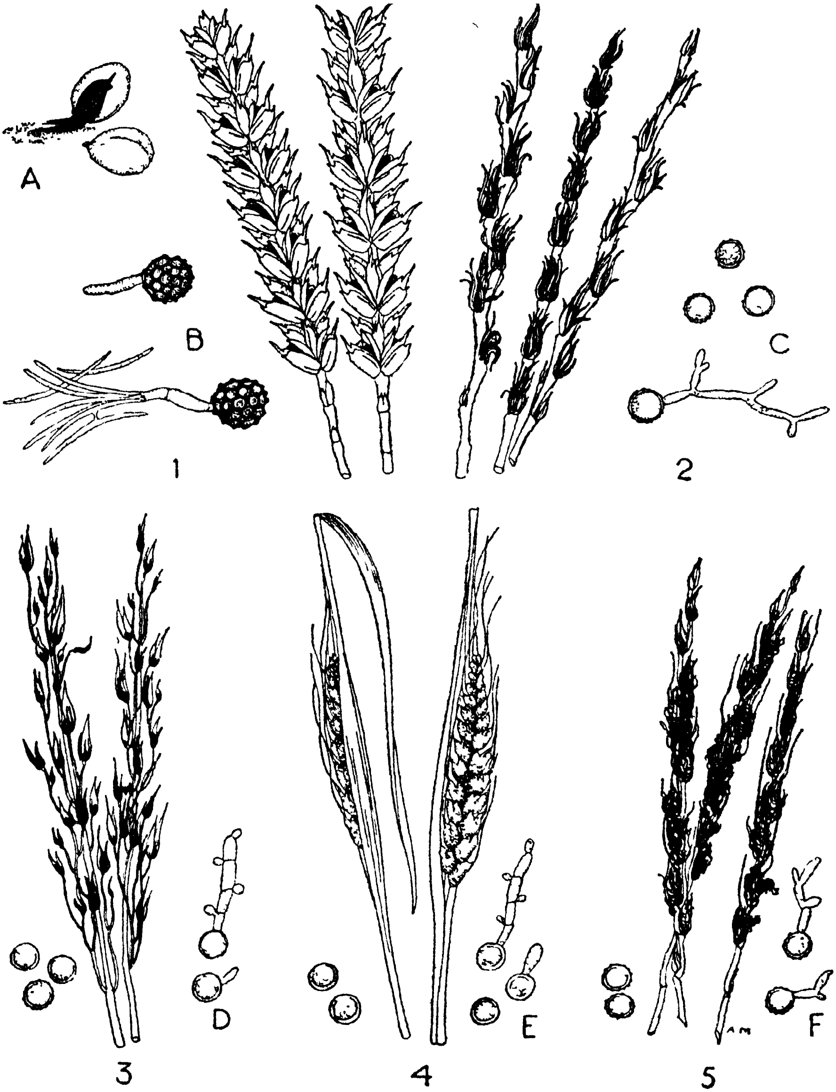


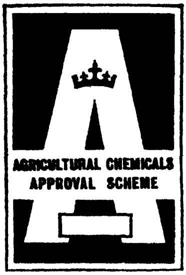
FIG. 66.—SMUT DISEASES.

1, Bunt of Wheat (*Tilletia caries*). A, bunt balls, B, germinating spores.
2, Loose Smut of Wheat (*Ustilago tritici*). C, germinating spores.
3, Smut of Oats (*Ustilago* spp.). D, germinating spores.
4, Covered Smut of Barley (*Ustilago hordei*). E, germinating spores.
5, Loose Smut of Barley (*Ustilago nuda*). F, germinating spores.

cannot be detected until the affected plant comes into flower. The young ears are then of a slightly darker green colour than those of healthy plants, and the chaffy scales open out a little more widely. At this stage the grains are deep green in colour and, when crushed, are found to be filled with a black greasy mass of spores which has an unmistakable fishy smell. As the plant ripens the symptoms become less clear, and by harvest time it is often difficult to distinguish them. Meanwhile, the spore-containing grains mature, developing into brownish, rounded structures known as " bunt balls ", each of which contains several million dark coloured brand spores.

When the crop is threshed many of the bunt balls are broken, and the spores are released and scattered over the healthy grain. If this is sown without treatment the spores germinate, giving rise to basidia which bear terminal clusters of narrow, sickle-shaped basidiospores which frequently fuse together in pairs. As the grain is germinating, hyphæ from the basidiospores penetrate into the young shoot and work their way into the tissues at the tip of the stem. As the stem elongates the growth of the fungus keeps pace with it, and the mycelium persists in the terminal growing point. When the flowers begin to form the fungus strands push their way into the tissue which normally gives rise to the grain, and then divide into millions of brand spores. Thus instead of a normal wheat grain developing a " bunt ball " is formed.

Control Measures. Covered Smut of wheat can be prevented by treating the seed before sowing with a suitable seed disinfectant. At one time weak solutions of copper sulphate or formalin were used, but both these wet treatments have certain disadvantages and have now largely been superseded by modern methods of seed disinfection using dust or liquid formulations of proprietary organo-mercury seed dressings. These products are manufactured by several different firms, but most of them bear the official approval mark (Fig. 67) of the Ministry of Agriculture, Fisheries and Food and the Department of Agriculture and Fisheries for Scotland.



[*Ministry of Agriculture, Fisheries and Food*]

FIG. 67.—THE APPROVAL MARK FOR INSECTICIDES AND FUNGICIDES.

A further development is the use of combined seed dressings containing an organo-mercurial or other fungicide for the control of seed-borne diseases, and an insecticide such as gamma B.H.C. or dieldrin for the prevention of wireworm or wheat bulb fly attack (see p. 429).

Seed already treated with one or other of these dressings can be obtained from most seed merchants, but with home-saved seed the mixing together of the grain and powder dressings can be done on the farm. The most effective way is with a machine of the barrel or churn type ; some models are power-driven, but simple and inexpensive hand-operated machines can be bought, or a home-made model can be constructed from a barrel or drum mounted so that it can be rotated by turning a handle. With machines of this type the mixing operation is done by churning the seed and powder together. Another method sometimes adopted, but which is not to be recommended owing to the likelihood of imperfect mixing and the risk of inhaling the dust by the operator, is that of carrying out the mixing operation in a sack or of spreading the grain on a barn floor, scattering the powder over it, and then turning the heap over three or four times with a shovel.

Provided the grain is kept dry before and after treatment, and the dressing is correctly used, there is no risk of injury to germination. If the grain is not well conditioned and is slightly damp, it should not be dressed in advance and stored, but should be treated immediately before sowing. Further, as the organo-mercury seed dressings are proprietary articles and contain a poison, they must be used as directed by the particular manufacturer and the appropriate precautions taken.

Loose Smut of Wheat (*Ustilago tritici*). The symptoms of Loose Smut differ from those of Covered Smut of wheat inasmuch as the soot-like mass of spores is set free by the breaking down of the ovary walls. This occurs when the healthy plants are in full flower, and by the time their grains have started to swell all that remains of the ears of infected plants is a blackened stalk. The spores, therefore, are not harvested with the crop but drift about in the air, some of them falling on the feathery stigmas of the healthy wheat flowers. When this happens they germinate directly, if conditions are favourable, giving rise to a mycelium which travels downwards into the ovary and then into the developing embryo. There is no visible effect of this on the seed, which ripens in the normal way. Nevertheless, although the grains appear to be healthy, they are infected internally, and when sown give rise to diseased ears, the mycelium growing upwards with the tips of the main and lateral shoots as in Covered Smut, and again forming brand spores at the flowering stage.

Control Measures. As the fungus is not on the surface of the grain but inside it, steeping seed wheat in copper sulphate or formalin, or dry dusting with organo-mercury seed dressings, will not prevent Loose Smut. Control is difficult because the mycelium within the seed must be killed without injuring the vitality of the grain itself. The only way of doing this is by means of a warm-water treatment, known after the name of its discoverer as Jensen's method. The first operation is to place the seed wheat in a sack, incompletely filled to allow for the subsequent swelling of the grain, and to immerse it in cold water for four hours. It is then taken out, drained for a few minutes, and submerged for ten minutes in a tank of warm water. During this period the temperature of the warm water must be kept between 52° C. and 54° C. (125°–129° F.) which is the critical temperature for the fungus. The margin of safety is very narrow, for if the temperature rises above 54° C. the vitality of the grain will be seriously affected, and if it falls below 52° C. the fungus will not be killed. After the sack has been taken from the warm water the grain is spread out in a thin layer on the barn floor to dry, and when dry is sown. Although this process is effective in preventing Loose Smut it requires very careful supervision otherwise the risk of injuring the grain is great, and for this reason it is not a practical treatment for the average farmer to carry out. The best way of avoiding Loose Smut is to select seed corn from crops which have not shown the disease. There are also considerable varietal differences in susceptibility, Hybrid 46 and Cappelle Desprez being most susceptible whilst Jufy I, Phoebus and Professor Marchal have a high degree of resistance.

Covered Smut of Barley (*Ustilago hordei*). The life cycle of this fungus, and the course which the disease takes, is very similar to that of Covered Smut of wheat, with the exception that the brand spores produce a basidium with cross walls on which are borne small rounded basidiospores.

The disease can be prevented by treating the seed with an approved organo-mercury seed dressing. This not only prevents Covered Smut but also Leaf Stripe, *Pyrenophora graminea*, an important seed-borne disease which may kill the seedlings or cause partial or complete blindness of the ears (see p. 372).

Loose Smut of Barley (*Ustilago nuda*) has a life-cycle similar to *Ustilago tritici*. The only remedial treatment is by Jensen's warm-water method. The procedure adopted is very similar to that for Loose Smut of wheat but, after the four hours' soaking in cold water, the grain is steeped for 5 minutes in water at 49° C. (120° F.) and then for 10 minutes in water kept as close as possible to 51° C. (124° F.). If the temperature is allowed to rise higher than this the grain may be damaged. Here again the best practical means of avoiding Loose Smut is to obtain seed from crops in which the disease has not been present. Among spring varieties, Rika is very susceptible and Proctor relatively resistant.

The Oat Smuts. The oat crop is also affected by two smut diseases, but it is often very difficult to distinguish them apart. Covered Smut is caused by *Ustilago hordei*, and Loose Smut, the more common of the two, by *Ustilago avenæ*. Unlike the fungi causing the other loose smuts, however, *U. hordei* and *U. avenæ* do not penetrate deeply into the grain. In both diseases active infection occurs from spores (or dormant mycelium) on the grain, and consequently they are amenable to chemical methods of seed disinfection.

Control Measures. Both the smut diseases of oats can be much reduced by disinfecting the seed with an approved organo-mercury seed dressing, and this treatment has the added advantage that it also prevents Leaf Spot and Seedling Blight, a seed-borne disease caused by the fungus *Pyrenophora avenæ*. Dressing seed oats with a solution containing 1 pint of commercial (40 per cent) formaldehyde in 40 gallons of water is a very effective treatment, but it has the serious disadvantage that it does not prevent Leaf Spot, and it is a treatment unlikely to be used except in special circumstances.

There are few farmers nowadays who do not disinfect their seed wheat to prevent disease, but unfortunately there may be some, especially with home-saved seed, who fail to adopt this simple precaution for barley and oats. Since the introduction of the combined seed dressings that are effective also against insect attack, however, it is probable that seed of all three cereals supplied through seed merchants is mostly treated.

The **Agaricales** is another Order in the Basidiomycetes (Subclass Homobasidiomycetes), and included in it are families such as the *Thelephoraceæ*, the *Polyporaceæ* and the *Agaricaceæ*. The fruiting bodies are mostly large and each basidium usually bears four basidiospores at its apex. A brief description of certain fungi in these families is now given.

Black Scurf and Stem Canker (*Corticium solani*). This is a disease of potato caused by a member of the family, *Thelephoraceæ*. Black scurf is descriptive of the appearance of the sclerotia of the fungus on the skin of affected tubers. These black, carbonaceous-like aggregates of mycelium are most conspicuous on moist tubers from which the soil has been rinsed, but on drying they lighten in colour and become less noticeable. They are readily detached with the finger nail and, as the mycelium does not penetrate the skin, the flesh of the tuber is unaffected. Such infected tubers used for seed can be a potential source of trouble to the resultant crop, especially in the early stages depending on seasonal and soil conditions. Slow growth resulting from cold wet soil or, on some of the lighter soils, prolonged dryness, can often predispose a crop to severe attack.

The growing tips of the young sprouts are readily attacked by the mycelium and become blackened and dead. The resultant lateral shoots may later be attacked similarly and, at worst, the tuber may fail to produce a plant. Shoots that manage to emerge are seriously weakened and the leaves may assume an appearance simulating primary symptoms of Leaf Roll, and can be mistaken for such unless the plant is pulled up and the stem canker condition observed on the below-ground parts. Under less severe conditions, although the mycelium may ramify over the below-ground parts of the plant to produce numerous brownish, slightly collapsed areas on otherwise relatively white roots, stolons and shoots, the plant survives and only the occasional shoot completely girdled by a stem canker succumbs. It is on such plants later in the season that the perfect stage is not infrequently seen as a thin, skin-like white felt enveloping the surface of the stem and spreading upwards for an inch or more above soil level. This is the " collar fungus " stage consisting of a hymenial layer bearing basidia of the fungus. The vegetative mycelium is branched and colourless at first, but later amber coloured. The branches arise at right angles and are constricted where they originate from the main hyphae. These are very characteristic features of the fungus as seen under the microscope.

Control Measures. A counsel of perfection would be to avoid planting tubers bearing black scurf. In Scotland and Northern Ireland it has been shown that potential infection from contaminated tubers can be reduced by disinfecting them with organo-mercury compounds, but the thicker sclerotia make fully effective control difficult. Boxing up and chitting the seed will enable weakly-sprouted tubers to be discarded before planting and at the same time afford greater latitude in the choice of favourable planting conditions.

Dry Rot (*Merulius lachrymans*). In the *Polyporaceæ* the fruiting bodies are fleshy, leathery or woody in texture, and they usually grow in the form of bracket-like structures standing out at right angles from tree-trunks. Their lower surfaces bear a hymenium or spore-bearing surface composed of tubes, the cavities of which are lined with basidia bearing basidiospores. The mycelium is confined to the wood, which in time is usually reduced by its action to powdery touchwood. Included in this family are species of *Polyporus* and *Fomes* (many of them wound parasites which are responsible for serious diseases of forest trees and hedgerow timber), and *Merulius lachrymans*, a most destructive fungus which causes Dry Rot of timber.

Dry Rot is comparatively rare in the open but it often occurs in farmhouses and farm buildings, where its destructive effects are well known. In any moist situation such as in cellars or in the space between the soil and a floor, it develops a vigorous mycelium in the form of a dense, white, felt-like sheet which can readily be stripped from the joists or floorboards. As this grows, thick strands of hyphæ, packed with nutrient material and capable of transporting water, are formed. These often grow to great lengths, not only on wood but also on the surface of brick walls, etc., with the result that wood far removed from the original source of infection may become attacked. An outbreak at soil level, therefore, may lead to the destruction of roof timbers. The surfaces of the mature fruiting bodies, which are rusty-brown, flat incrustations 6 in. or so across, are covered with folds and wrinkles forming a series of shallow pits, the surfaces of which are lined with basidia. These produce such enormous quantities of spores that the first symptom of the presence of the fungus, apart from its characteristic mouldy smell, is the accumulation of a rust-coloured dust on floors, shelves and furniture.

When the spore-bearing stage has been reached the wood is usually so badly affected that the next symptom is the sagging of beams or the collapse of the floorboards. The spores germinate readily on moist wood and quickly give rise to the mycelial sheets. The hyphæ of these invade the wood, partially destroy the cell walls and reduce it to a spongy, brownish mass which readily absorbs and retains water. When dry, the decayed portions shrink and crack, and the fissures forming at right angles to one another divide it into cubical blocks which can easily be rubbed down into a powder.

Control Measures. Where an outbreak occurs it should be dealt with immediately. Every piece of wood which has been reached by the mycelium should be cut out and replaced with sound timber which has been thoroughly brushed over with a suitable wood preservative. Precautions should then be taken to prevent a further attack. As the growth of the fungus is dependent on a supply of moisture, an endeavour should be made to trace this to its source and prevent its further access. One of the commonest points of entry, especially in old buildings where damp courses are non-existent or inefficient, are joists let into walls at or below the soil level. An external surface drain will do much to keep such a wall dry, and the liberal use of creosote, both on it and on the end of the joists inserted in it, should stop any fresh infection. Provision should also be made for a thorough ventilation of the space enclosed between the ground and the floorboards.

The Honey Fungus (*Armillaria mellea*). This is one of the *Agaricaceæ*, or Gill Fungi, such as mushrooms and toadstools, the basidia being formed on gill-like plates radiating from a common centre. Most of the Gill Fungi are saprophytes, but *Armillaria mellea*, the Honey or Shoe-string Fungus, is parasitic, causing a serious root rot of trees.

The mushroom-shaped fruiting bodies are formed in large clusters at the base of infected trees or on stumps which have been left in the ground. They are honey-yellow in colour and the top of the cap bears many dark brown, fibrous scales. If the bark of an infected tree is stripped off, a vein-like network of strands, or rhizomorphs, not unlike black leather bootlaces, will be found on the surface of

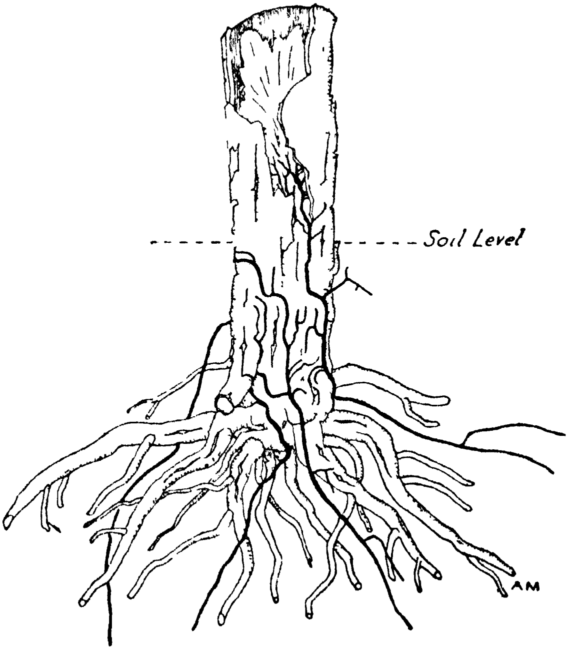


FIG. 68.—ARMILLARIA ROOT ROT (*Armillaria mellea*).
Rhizomorphs on root.

the wood. These pass over in their younger portions to delicate white sheets of mycelium, the hyphæ of which penetrate and destroy the tissues of the wood (Fig. 68). They also spread through the soil, travelling for considerable distances at a depth of about 4 in. On coming into contact with a sound root, their hyphæ penetrate between the crevices of its bark and develop rapidly between it and the wood. Once the roots have become infected and the mycelium has worked its way round the base of the tree, it dies suddenly.

Control. The disease is difficult to control. Cutting down infected trees is of little use since the fungus can grow as a saprophyte on their stumps, and even if they are uprooted rhizomorphs may still be left in the soil. Sometimes, however, these can be prevented from spreading by digging an open trench, about a foot deep, around each infected tree.

DISEASES CAUSED BY DEUTEROMYCETES

In the *Deuteromycetes* or *Fungi Imperfecti* there are no sporangia, asci or basidia in the life-cycle so far as is known, and only asexual spores, chiefly conidia, are formed. These are usually borne on hyphæ or groups of hyphæ (*Moniliales*), on cushion-like masses of hyphæ (*Melanconiales*) or in pycnidia (*Sphæropsidales*). An example of the pycnidial type is the fungus causing Leaf Spot of celery, and examples among the fungi included in the *Moniliales* are those causing Eyespot of wheat and barley, Verticillium Wilt of lucerne and Dry Rot of potatoes.

Leaf Spot of Celery. Celery Leaf Spot is a seed-borne disease caused by *Septoria apii* and *S. apii-graveolentis*. On the " seed " coat of infected samples minute black spore cases (pycnidia) occur, and it is these which contain the spores which bring about infection. When released, the spores infect the seed leaves, and later the other leaves become infected also. Symptoms are the presence of numerous pale green spots studded with tiny black spore cases. If weather conditions favour the spread of Leaf Spot the affected areas increase in size, the spots merge together and the leaf tissue shrivels and dies.

Control Measures. Leaf Spot infection in the field and in seed beds can be kept in check by spraying with a protective fungicide, and Bordeaux mixture was at one time extensively used, the treatment being repeated as necessary at intervals of two or three weeks. The best way of avoiding Leaf Spot, however, is to sow clean seed, or seed that has been freed from infection by hot water treatment. If properly carried out this will ensure complete freedom from infection and the treatment should perhaps be applied to all seed. It consists of the immersion of the seed for 25 minutes in water maintained at 122° F. followed by careful drying. The effect on germination, though slight, is more pronounced on old seed. Treatment is, therefore, best done on young seed even if it is subsequently stored.

Healthy seed can be produced if plants intended for seed production are kept substantially free from infection by regular spraying with a protective fungicide from the seedling stage until the time of seed formation. The most important applications are when the plants are flowering and setting seed. Seed heads must be supported to prevent possible infection through contact with the lower leaves.

Eyespot of Wheat and Barley. Eyespot is caused by the fungus *Cercosporella herpotrichoides*, which attacks all commercial varieties of wheat and barley, especially autumn-sown crops. Oval or eye-shaped areas with brown borders, and small black dots in the middle of the areas, appear in spring on the leaf sheaths just above soil level. The fungus weakens the individual straws, which tend to fall over in all directions : this straggling is quite different from the lodging caused by storms or excess of nitrogen, in which the crop usually collapses in one direction. Infection is spread by spores spread in rain splashes.

Control Measures. A sound rotation in which wheat and barley do not occur too frequently is the best way of preventing eyespot, but a two-year break will usually reduce infection substantially. Oats and ryegrass are relatively non-susceptible and can be used in the rotation to reduce eyespot. A thin seeding, together with balanced manuring, also helps to reduce losses from this disease.

Verticillium Wilt of Lucerne (*Verticillium albo-atrum* and *V. dahliæ*). Observed in this country in recent years, this disease is now commonly found wherever lucerne is grown. Field symptoms occur from June to September and consist at first of the flagging of the upper leaves of infected plants during warm, bright periods, often with recovery in the cool of the evening. As infection proceeds, the lower leaves wilt permanently, turn yellow and later become bleached and dried up. They are then readily shed to produce defoliation. These symptoms intensify progressively from the base of the shoots upwards, and the stem bases become enveloped in a greyish growth of sporophores. Internally the xylem tissues are stained, and in completely wilted plants this dark-brown discoloration may extend throughout the vascular system of the plant. As the stems die the bases become blackened due to the formation in the cortex and epidermis of resting mycelium or, with *V. dahliæ*, micro-sclerotia.

The disease can be introduced with the seed on infected plant fragments to produce scattered infections in the resultant crop. Subsequent spread can be rapid by means of air-borne spores and fragments of diseased plants, both of which are spread widely by implements such as grass-cutters and forage harvesters. Severe infection localised near gateways and round the headlands is often indicative of introduction of the disease from another crop by contaminated implements.

Control Measures. Organo-mercury and thiram seed dressings have shown promise in controlling introduction of the disease with seed, and on the farm some measure of success in localising outbreaks may attend disinfection of machinery and footwear with formalin before moving from infected fields. If possible, infected areas should be cut last.

Importation of seed from Verticillium-free areas offers a means of avoiding introduction with the seed, and so far there has been no record of this disease in America. Promising, too, is the occurrence of varietal differences in susceptibility which may be exploited by the plant breeder to produce resistant varieties.

Dry Rot of Potatoes (*Fusarium spp.*). One of the most destructive diseases of stored potatoes in this country, especially of early varieties, is Dry Rot caused by species of *Fusarium*, of which the most important is *F. caeruleum*. Although the fungus is soil-borne, the disease does not affect the growing plant but occurs on mature tubers after storage, infection having taken place from adhering soil particles. Susceptibility to infection increases with maturity of the tuber and the disease develops most rapidly at about 60° F. in conditions of high humidity. Early stages of infection appear on the surface as brown patches overlying a brownish rot somewhat reminiscent of Blight. Internal shrinkage of the rotting tissues, however, soon results in the very characteristic concentric wrinkling of the overlying surface and the development of cavities within the rotted tissue. At this stage pink, white or bluish pustules of the fungus begin to break through the skin to produce large numbers of spores. Microscopically, these are characteristically sickle-shaped and multi-septate. In some spores, individual cells may become thick-walled resting spores and enable the fungus to survive unfavourable conditions. Where infection is severe in large bulks of potatoes, soft-rotting bacteria often supervene resulting in overheating and extensive losses.

The fungus is essentially a wound parasite and enters through cuts and abrasions. This may occur at lifting time, but as susceptibility increases with tuber maturity, mechanical injuries sustained late in storage are especially subject to infection. Most early varieties are very susceptible, Arran Pilot especially so, and, of the main crop varieties, the once widely grown Doon Star is also very susceptible.

Control Measures. Mechanical damage to the tubers at lifting time and subsequently should be kept to a minimum, and all unnecessary handling during storage should be avoided. For tubers intended for seed, early grading and boxing up is advisable, and subsequent " picking over " should be avoided until as near planting time as possible. Dipping tubers in an organo-mercury disinfectant will give satisfactory control provided this is done immediately on lifting. Tubers affected with Dry Rot should not be planted as they usually rot in the soil and result in a gappy crop.

VIRUS DISEASES

In addition to the diseases caused in agricultural crops by the attacks of such microscopic organisms as fungi and bacteria, there is a large group of diseases which falls into quite a different category. These are known as *virus diseases* and they must be considered as a class apart because they differ fundamentally both in appearance and treatment from disorders due to bacteria or fungi.

The word "virus" comes from the Latin and means literally a poison, but in its modern sense it refers only to a particular kind of disease agent. Viruses are not only of extreme importance from the practical point of view since they cause disease in every kind of living organism from bacteria to man, but they are of great scientific interest. They may be regarded as a kind of link between the

" living " organism and the " non-living " chemical substance, and they possess certain properties of both organisms and chemicals.

It is necessary to emphasise at this point a few of the outstanding characteristics of viruses in order to explain more clearly how they differ from other disease agents. Viruses are often referred to as " filterable " or " ultramicroscopic ", and this denotes one of their chief characteristics—their extremely small size. Most viruses, and all those which attack plants, are too small to be seen even with the best microscope using visible light, and this property also allows them to pass through filters which hold back even the smallest bacteria. Another characteristic of viruses is the fact that unlike so many microscopic organisms, they cannot be cultivated in an artificial nutrient medium such as broth or agar : viruses must have a living cell in which to multiply.

The method of spread of viruses is another important characteristic because it may govern to a large extent the control measures to be applied to the disease. Viruses depend in many cases upon an insect, eelworm or other organism to transmit them from the diseased to the healthy individual. This is true not only of plant viruses but of some animal viruses also, yellow fever and the mosquito for example. Of the insects concerned with the spread of plant virus diseases, aphids or greenfly are perhaps the most important, although thrips, leaf hoppers and flea beetles are vectors of a number of viruses of economic importance. Free-living eelworms (*Xiphinema* and *Longidorus* spp.) in the soil too have been shown to carry soil-borne viruses that affect strawberries and a number of other hosts. In a few virus diseases, infection may be carried on or in the seed ; of these, lettuce mosaic is an outstanding example.

Viruses are the cause of disease in all types of organisms. Yellow fever, small-pox and influenza in man ; foot-and-mouth disease in cattle ; dog distemper ; fowl pox, are all virus diseases : a large number of separate and distinct viruses cause disease in plants of every kind. From the agricultural point of view there are certain viruses which are of first-rate importance, such as those which attack sugar beet, potatoes and cruciferous crops, particularly cauliflowers, broccoli and other brassicæ. In this article attention will be mainly confined to the virus diseases of these crops: *Barley Yellow Dwarf* virus, which attacks cereals and grasses, is not discussed.

VIRUS DISEASES OF SUGAR BEET AND MANGELS

Two of the viruses attacking sugar beet and mangels in the British Isles are those causing Mosaic and Virus Yellows respectively, the latter being the more important disease of the two. In the first disease the symptoms consist of a mottling of light and dark green on the central leaves somewhat resembling a mosaic pattern ; this mottling is brightest on the youngest leaves. On the whole, the effects of the disease on the growth of the plant are not very severe.

Sugar Beet Yellows. In sugar beet yellows there is no mottling but the leaves assume a uniform yellowing which is confined to the older and outer leaves. In addition, the texture of the leaves is changed and they become extremely brittle and crackle underfoot. This is a very serious disease as farmers in East Anglia know to their cost, and it may cause a drop in yield from 15 tons to 3 tons to the acre.

It is important to realise that, once a sugar beet or mangel plant is infected with these virus diseases, it is too late to do anything about it. The plants cannot be cured by any kind of chemical treatment. Therefore efforts must be made to prevent the plants becoming infected, and the first step in this direction is to understand how the viruses are brought to the plants. As mentioned earlier, many plant viruses depend entirely on insects for their spread and the insect rectors mostly associated with the spread of viruses affecting agricultural crops are aphids or greenfly. More than one species of aphid may be concerned in the spread of a particular virus but not any other kind of insect. In the field, mosaic and yellows of sugar beet are spread by two species of aphid, the small green potato and peach aphid (*Myzus persicæ*, Sulz.) and the common black bean aphid (*Aphis fabæ*, Linn.), and not by any other means. So far as is known at present the virus is not transmitted through the seed.

Control Measures. Control measures must therefore be developed to prevent infected aphids gaining access to the sugar beet and mangel crops, or to kill any aphids arriving on the crop by spraying with a systemic insecticide. Although this may be too late to prevent an infective aphid from transmitting the virus to the plant on which it has fed, build-up of aphid infestation is prevented and transmission of virus from plant to plant within the crop is reduced substantially. Any measures which help to reduce the sources of infection are useful because an aphid must first feed on an infected mangel or sugar beet before it can infect a healthy plant. Volunteer beets or mangels which are often heavily infected are a common source of virus infection. The sprouts of clamped mangels and fodder beet held late into the season can be very dangerous in this respect. A crop heavily infected in July may lose 50 per cent of its sugar. Another important measure is the isolation as far as possible from the root crops of sugar beet and mangels, of the steckling beds which can be heavily infected with virus. Late sowing of the steckling beds is also recommended, the idea being that the stecklings should not germinate till the aphids have left the root crop, which may be sometime in August. Spraying the stecklings with a systemic insecticide such as demeton-methyl or schradan when they have the first pair of leaves, and subsequently at fortnightly intervals, will prevent aphid infestation. A last application at the end of October will safeguard against any that might otherwise over-winter.

Put very briefly, the following are the recommendations for the control of the virus diseases of sugar beet and mangels :

(1) Isolation of the steckling beds as far as possible from root and seed crops of sugar beet and mangels.
(2) Late sowing of the stecklings.
(3) Spraying of the steckling beds with a systemic insecticide to reduce aphid infestation.
(4) Destruction of the steckling beds if heavily infected with virus.

(5) Early sowing of the sugar beet crop, and spraying with systemic insecticides as soon as aphids begin to build up on the plants.

(6) Destruction of sources of infection such as volunteer beets and mangels, and the early removal of mangel clamps.

VIRUS DISEASES OF THE POTATO

The potato plant is subject to infection with a number of different viruses and their study is difficult and complicated. From the viewpoint of the practical grower the virus diseases of the potato may be divided into two categories, (1) " Leaf-roll " disease due to infection with one specific virus, and (2) the various virus diseases which make up " Potato Mosaic."

Leaf-roll. In potato Leaf-roll, the outstanding symptom is the rolling of the leaves. The rolling takes place upwards and inwards, and the leaves themselves are thickened and yellowish in colour. In some potato varieties there may be a purple coloration of the leaves together with the formation of small aerial tubers. The whole plant is dwarfed and stunted and the yield may be reduced by 70–90 per cent. Some potato varieties, e.g. Up-to-Date, are very susceptible to leaf-roll, others such as Arran Banner and Majestic are less so.

The virus of potato leaf-roll is carried from diseased to healthy plants in the field by the agency of aphids. The aphid chiefly responsible is the potato and peach aphid, *Myzus persicæ*, though one or two other species play a minor part in the spread of the virus.

Potato Mosaic. In this disease several viruses are concerned, the most important being severe mosaic, sometimes called *Leaf-drop streak*. The virus causing this disease is known as potato virus Y and is spread by the same potato aphid transmitting leaf-roll. The first signs of infection appear as dark streaks on the veins of the under sides of the leaf. These streaks increase in size and coalesce, causing the whole leaf to shrivel and hang down ; it is from this character that the name " Leaf-drop " is derived. These leaves usually remain attached to the stem, on which there frequently develops a longitudinal streak. The symptoms described above are those of a current season infection ; in subsequent years there is less leaf-drop but the plant is stunted with mottled, distorted leaves.

Potato virus A is another aphid-transmitted virus similar in some ways to potato virus Y.

Another common mosaic disease of the potato is known as *Potato Mottle* or *Mild Mosaic*, the chief symptom being a mild mottling of the leaves with light green or paler spots and patches. On some varieties, however, such as Epicure, King Edward and Ninetyfold, the disease takes a different form, and instead of a mottling of the leaves the growing point and young leaves are killed. This type of disease is known as *Top Necrosis*, and plants reacting in this manner are considered to be field immune to the virus since it does not spread from such plants. The causative virus of potato mottle is known as potato virus X and it differs in many ways from potato virus Y, chiefly in that so far as is known it is not insect-transmitted, but spreads by contact of the leaves of diseased and healthy potato plants.

Potato virus X is exceedingly common, sometimes latent, in many varieties of potatoes and is present in much of the Scotch Stock Seed. Some varieties, such as Kerr's Pink, are almost universally infected.

Potato Crinkle is a composite disease and is due to the two viruses A and X acting in unison ; a somewhat similar disease is caused by the two viruses Y and X. The symptoms of crinkle are severe ; the plant is bushy and dwarfed and the leaves show a pronounced puckering and downward curling. Diffused yellowish areas occur all over the foliage, which is brittle and easily injured.

Control of Potato Virus Diseases. In a crop like the sugar beet or mangel discussed above, it is easy to start with a clean crop because beet is grown from seed and few viruses are seed-transmitted. With the potato crop, however, the state of affairs is different. The " seed " potato is a method of vegetative propagation, and all vegetative parts of a virus-infected plant give rise to a plant similarly diseased. For this reason the virus problem is vitally important in all crops which are raised from cuttings, tubers, runners, etc., and this includes such crops as potatoes, strawberries, raspberries, hops, dahlias and all flower bulbs. The reason why the English potato grower obtains fresh seed potatoes from special seed-producing areas every year lies in their comparative freedom from insect-borne virus infection. The first essential, then, is to start with as clean a crop as possible. This can be achieved by using first-quality commercial seed potatoes with an " A " certificate (see p. 260).

Another important point is to avoid, as far as possible, the insect vector which spreads the viruses. One way to do this is by the choice of a suitable site for growing the potatoes. Aphids will not fly if there is a wind blowing at more than 4 m.p.h., if the temperature is lower than 65° F. and if relative humidity is more than 75 per cent. These conditions hold in the Scotch and Irish districts where the best seed potatoes are grown and in many of the hill areas in western parts of England and Wales at altitudes above 400 feet. It is also well to remember that the important aphid overwinters as an egg on peach trees, that it breeds in glasshouses on various plants all the year round and that it may also spend a mild winter out of doors on cabbages or brussels sprouts. All these facts should be borne in mind when growing potatoes, especially crops destined for seed. A certain amount of control of potato virus diseases is possible by carefully roguing out and burning infected plants and any tubers that may be on them. Such roguing should be done when the plants are small, firstly because they are easier to remove and will not have infected their neighbours with virus X by contact of their foliage ; and secondly because they will not have formed tubers which might be left behind in the soil.

In recent years it has been shown that the useful life of seed stocks in the ware-growing districts can be extended if either the ware crop from which seed is to be saved, or a special area planted for seed, and isolated from the ware crop, is sprayed with an insecticide to prevent the build up of aphids. This, combined with careful roguing, makes possible the production of home-saved seed even in ware-growing areas. The project requires great care to ensure success.

VIRUS DISEASES OF CRUCIFEROUS CROPS

Of late years growers of cauliflowers, broccoli, brussels sprouts and turnips have been perturbed at the damage done to these crops by virus infections. There are several viruses concerned but only the more important ones are dealt with here.

Cabbage Black Ringspot attacks cabbages, cauliflowers and turnips, besides various ornamental plants belonging to the same family, such as wallflowers, stocks, arabis, etc. On cabbages, cauliflowers and brussels sprouts the symptoms of the disease consist of black, ring-like spots on the leaves which frequently coalesce, forming patches of dead tissue. As the disease progresses the veins and midribs become blackened and the leaves turn yellow. Diseased plants are stunted and useless for market. Affected turnips are badly crinkled and distorted and make little growth.

Cauliflower Mosaic. Here the first sign of infection is a yellow clearing or intensification of the colour of the veins of the youngest leaves, a symptom which is absent in the Black Ringspot disease. This is followed by a veinbanding, consisting of narrow dark-green areas parallel to and adjoining the midrib and lateral veins. The effects of this disease are severe and the head or curd of cauliflowers is greatly reduced in size.

Both these viruses are aphid-transmitted, the two most important aphid species being the mealy cabbage aphid, *Brevicoryne brassicæ*, and the peach and potato aphid, *Myzus persicæ*. No very efficient control methods for these diseases are known, but any measures which reduce aphid numbers are helpful since the diseases cannot spread in the absence of these insects. Brassica plants are frequently infected in the seed-bed, so that effort should be made to protect the seedlings from aphid infestation. Screening the young plants by planting barrier crops round the seed beds, and spraying with a systemic insecticide, are possibilities.

Self-sown plants and plants remaining after the harvesting of a brassica crop should be destroyed as soon as possible, as these form a serious reservoir of inoculum from which virus can be spread.

Turnip Yellow Mosaic has in recent years become prevalent in brassica crops in the north-east of England. The virus is transmitted by the common turnip flea beetle and this is unusual since the beetle is a biting insect. Apparently only insects with biting mouthparts can carry this virus. The first sign of infection is the appearance of yellowing along the veins of the young leaves, and this is followed by an intense yellow mottling which resembles a variegation. The virus attacks turnips, swedes, kale and radishes, and can also affect the weed, shepherd's purse. Cabbages and cauliflowers are not easily, if at all, infected.

BACTERIA

The bacteria are a group of unicellular organisms resembling the fungi in their mode of nutrition but differing from them in their method of growth. They are exceedingly minute, the largest of them seldom being more than ten thousandths of a millimetre in length. Their shape may be that of spheres, long or short rods, commas or corkscrews. Multiplication is effected by the simple division of the individuals into halves, the new ones so formed either becoming separate or remaining united in chains, sheets or solid masses when the divisions take place in one, two or three planes respectively. The successive splittings follow with great rapidity, and a single cell may become two within twenty minutes after its formation if the conditions for growth are favourable. Reproduction may also be effected by means of spores formed either internally or by the thickening of the cell wall. The spores are highly resistant to extremes of temperature and to drought, and consequently they provide the bacteria capable of forming them with a resting stage. Many species are motile owing to the presence of one or more cilia.

It is difficult to realise the great importance of the group to mankind. They are mainly responsible for the decomposition of the organic matter built up by plants and animals. To counteract this, in the case of materials required as food, various processes of preservation, such as cold storage, canning, bottling, desiccation, pickling, and so on, have had to be devised. They play a great part in the manufacture of various dairy products, in which their activity is often brought under control by sterilising, with the object of destroying unwanted species, or by the addition of pure cultures of those known to produce the required results. In the soil and manure heaps their development determines the production, or in some cases the destruction, of essential nitrogenous plant food materials, as well as the reduction of cellulose-containing tissues to humus.

They are, however, better known generally as the causative organisms of many diseases, such as typhoid, cholera, tuberculosis and diphtheria. Plants are also attacked by them and one of the diseases they can cause, Fire Blight of pears, has been most disastrous in its effect on pears growing in this country since its discovery in Kent in 1957. Many thousands of affected trees have been grubbed under Orders served under the Destructive Insects and Pests Acts in an attempt to eradicate it. A number of other bacterial diseases, fortunately of no great importance, affect agricultural crops. Examples are, Blackleg of potatoes (*Bacterium phytophthorum*), Soft Rot of turnips (*Bacterium carotovorum*) and Crown Gall of sugar beet (*Bacterium tumefaciens*). On the other hand, the peculiar association of bacteria and leguminous plants, hardly to be described as a disease, is a matter of great economic significance.

The Nodules of Leguminous Plants. The clovers and leguminous plants in general have been described as " nitrogen-accumulators " because their tissues contain, mostly in the form of proteins, an unusually large percentage of nitrogen. This is evident when a comparison is made of the average total nitrogen percentage in the seeds of a number of the cereals and of the pulses :

Cereals		Pulses	
Maize . . .	1·8 per cent	Peas . . .	4·3 per cent
Buckwheat . .	1·9 " "	Beans . . .	4·6 " "
Oats . . .	1·9 " "	Lentils . . .	4·7 " "
Wheat . . .	2·3 " "	Soya beans . .	6·1 " "

Moreover, these plants can build up the large quantities of protein represented by these figures when growing on soil deficient in nitrogenous food materials. In fact, crops such as lupins can be grown satisfactorily on sandy soils incapable of carrying any non-leguminous crop, and their growth actually enriches the soil sufficiently for it to be used as a method for bringing such land under general cultivation. The value, too, of the nitrogen-collecting clover as a preparation for the wheat crop has been realised for several centuries.

If the seeds of a leguminous plant are sown in sand to which all of the essential elements except nitrogen have been added, the resulting plants grow normally until the reserves of food stored in their cotyledons are exhausted. Growth then ceases, the leaves become yellow, and the plants look as if they would die. Any other kind of plant under such conditions would soon perish through nitrogen starvation, but leguminous plants suffer a temporary check only, and almost suddenly recover and grow away normally. The root system of these plants differs from that of all other agricultural plants in bearing numbers of nodules on the main and lateral roots (Fig. 69). These begin to develop at an early stage of growth, and reach a size varying from that of a small pin's head to that of a pea, or even greater. Further, they fail to form when the plants are raised under completely sterile conditions, but their development can then be induced by the addition of traces of freshly crushed nodules to the soil or other medium in which the plants are rooting.

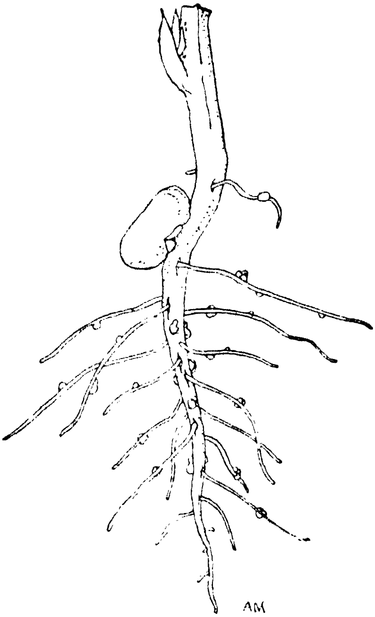


FIG. 69.—NODULES ON THE ROOTS OF FIELD BEAN.

Sections cut through fresh nodules show that they have the usual structure of roots but that the pith is more strongly developed and of a pale red or greenish-grey colour instead of white. Appropriate staining methods show that the cells composing it are crowded with somewhat irregularly shaped bacteria. These can be isolated from young nodules and cultivated on suitable, artificial media. Cultures from different species of leguminous plants show differences which suggest that a number of distinct strains of the organism *Rhizobium leguminosarum* exist. This view is supported by the fact that the bacteria isolated from peas fail to produce nodules on lupins or red clover.

Inoculation of Soil and Seed. The nodule-forming organisms are generally present in agricultural soils, so that when a leguminous crop is sown its roots soon become infected and, generally speaking, the more abundantly the nodules are formed the better the crop grows. Exceptions occur, however. The organism responsible for nodule formation on the roots of lucerne has not the wide distribution of that occurring on the roots of red clover, and where it is lacking the establishment of a lucerne crop is impossible. This probably accounts to a certain extent for the limited area under this crop. Again, the form responsible for nodule formation on the roots of the soya bean is apparently lacking in the soils of this country. Such deficiencies can readily be overcome by inoculating the soil with the appropriate form. This can be done by scattering a few sacks of soil, taken from a field on which the crop is known to thrive, over the surface. The general practice nowadays, though, is to use cultures of the required organism. When, for instance, lucerne is to be grown on a soil which has not carried the crop previously, especially in a district where it is not already in cultivation, a culture of the lucerne nodule organism is purchased, diluted down according to the instructions provided with it, and then poured over the seed. The essential organism thus finds its way into the soil ; it then infects the root hairs of the young plants directly, and quickly gives rise to a crop of nodules.

The growth of the bacteria in the tissue of the host plant is dependent on the supply of carbohydrates which they can obtain from it. Utilising this material as a source of energy, they build up directly from the inert atmospheric nitrogen nitrogenous foodstuffs which, on their death, become available for the use of the host plant. Host and invading organism are thus essential to one another. Such a relationship, so strikingly different to the types previously described, is known as " symbiosis ".

Chapter XIV

INSECT AND OTHER PESTS OF CROPS AND STOCK

INSECTS AND ALLIED ANIMALS

ANIMALS from four great groups are important on the farm either as pests or benefactors :

ANNELIDA (or segmented worms)—Earthworms ;
NEMATODA—Round-worms and Eelworms ;
MOLLUSCA—Slugs and Snails ;
ARTHROPODA (or animals with jointed limbs)—Insects, Woodlice, Spiders, Mites, Millipedes and Centipedes.

Earthworms have a long cylindrical body consisting of many similar rings or segments (Fig. 70). They have neither antennæ nor legs and move through the soil with the help of stout bristles. They are hermaphrodite, i.e. each individual combines both sexes, but cross-fertilisation is usual. Worm eggs are enclosed in a " cocoon " and newly hatched worms have the same form as adults. Earthworms should be present in all agricultural soils since they assist in breaking down organic matter and their burrows loosen and aerate the soil.

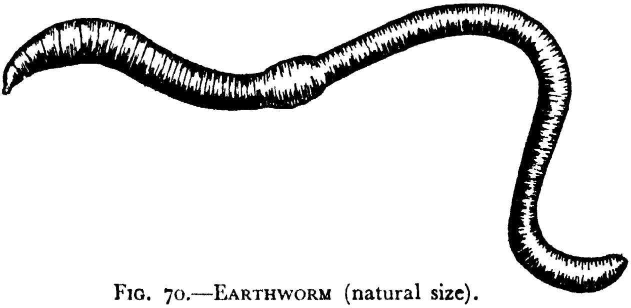


FIG. 70.—EARTHWORM (natural size).

Round-worms and Eelworms have the same shape as earthworms but their bodies are smooth and unsegmented. They have a stout, muscular body-wall which gives them great flexibility (Fig. 85). Males and females are separate individuals and eggs are produced by the females after fertilisation. Many round-worms and eelworms are parasitic in stock and crops.

Slugs and Snails have a soft unsegmented body which is withdrawn under a fold of the body-wall, the *mantle*, when the animal is at rest. The conspicuous spiral shells characteristic of snails are secreted by the mantle, as are also the small shells hidden under the mantle of slugs. In slugs (Fig. 71) and snails the head bears two pairs of retractable tentacles, the upper pair carrying the eyes. The mouth has a strap-like tongue, the *radula*, with transverse rows of teeth. The ventral surface of the body is flattened into the broad muscular foot which expands and contracts as the animal moves. The whole body is thickly coated with slime which gives some protection from the effects of adverse weather, from the action of irritants present in soil and also from the attacks of enemies. Slugs and snails are hermaphrodite but reproduce by cross-fertilisation, each individual acting as both male and female. Slugs are major pests of farm and garden crops, and a small green fresh-water snail, *Limnæa*, the mud snail, is the host of liver-fluke, a parasite of sheep.

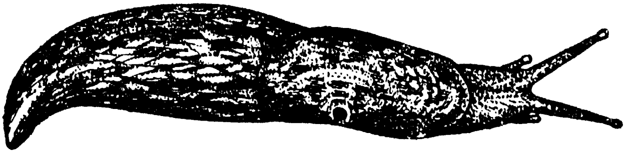


FIG. 71.—GREY FIELD SLUG : × 2.

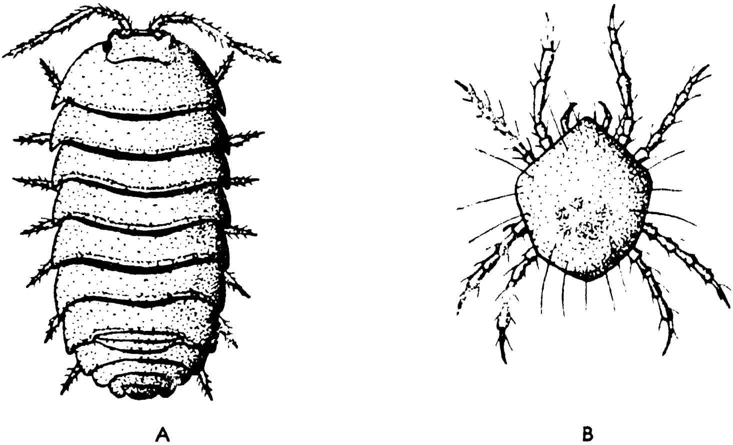


FIG. 72.—A. COMMON WOODLOUSE (*Armadillidium*) : × 6.
B. RED SPIDER MITE : × 25.

From *Insect Pests of Glasshouse Crops*, by H. W. & M. Miles (Crosby Lockwood).

Arthropoda. The fourth group of animals, the Arthropoda or animals with jointed limbs, consist of four main groups :

1. CRUSTACEA—Woodlice, Shrimps, Crabs and Lobsters.
2. ARACHNIDA—Spiders, Mites, Ticks and Scorpions.
3. MYRIAPODA—Millipedes, Centipedes and Symphylids.
4. HEXAPODA or INSECTA—Insects.

1. Woodlice (Fig. 72) and their allies have five or more pairs of

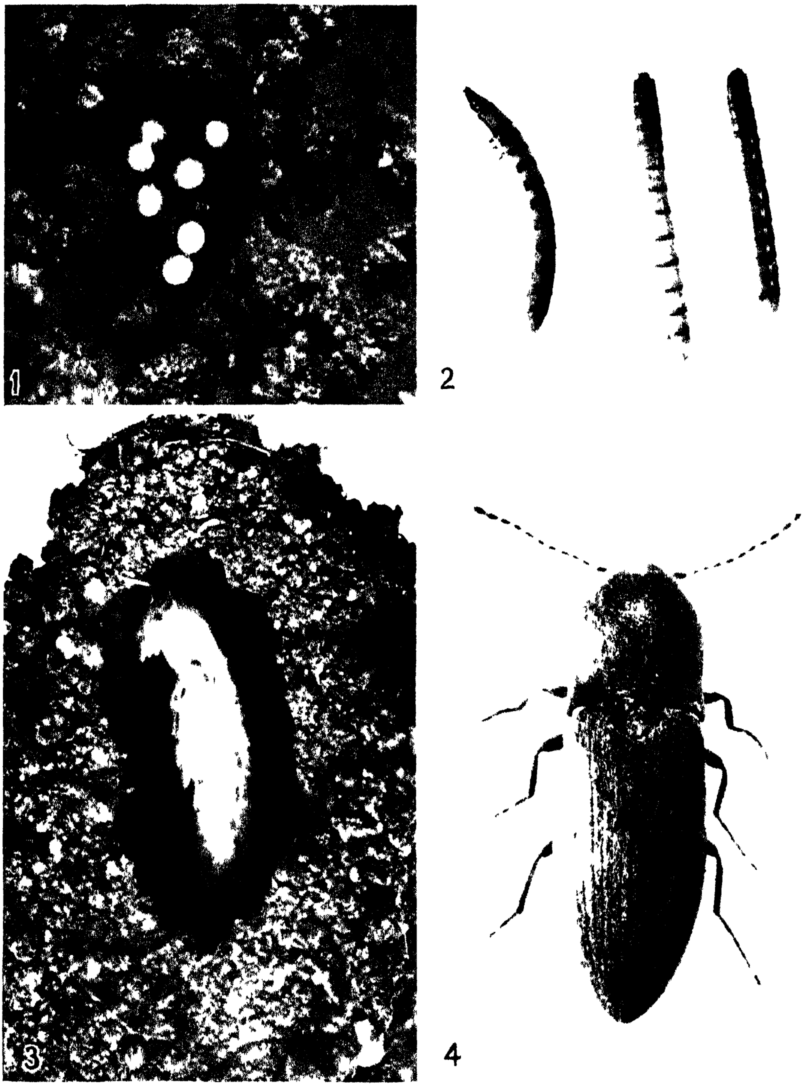


PLATE XIX. THE CYCLE OF THE WIREWORM (*Coleoptera*)

1, eggs (× 10); 2, wireworms, the larval stage (2); 3, the chrysalis in soil cell (×
4, the click beetle, the adult stage, *Agriotes obscurus* L. (× 6)

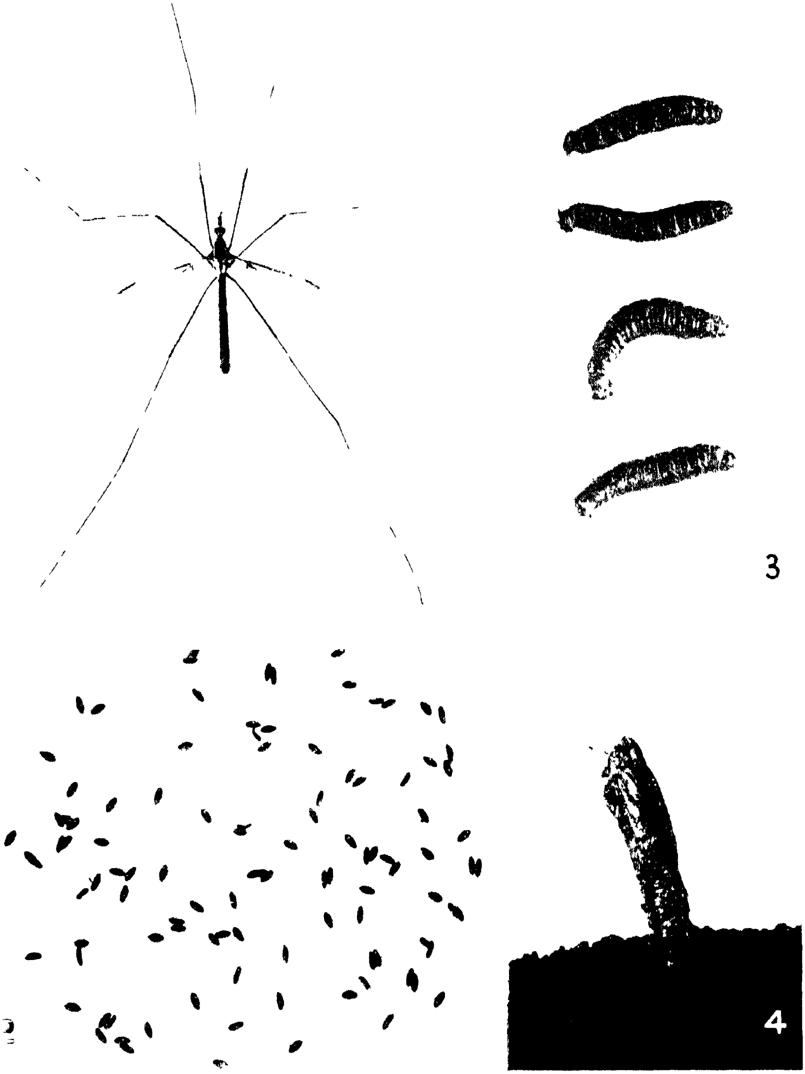


PLATE XX. LIFE CYCLE OF THE LEATHER JACKET (*Diptera*)

the crane fly, the adult stage, *Tipula paludosa* Meig. ♂; 2, eggs (× 3); 3, leather kets, the larval stage (nat. size); 4, chrysalis protruding from soil and ready for the emergence of the adult (× 2)

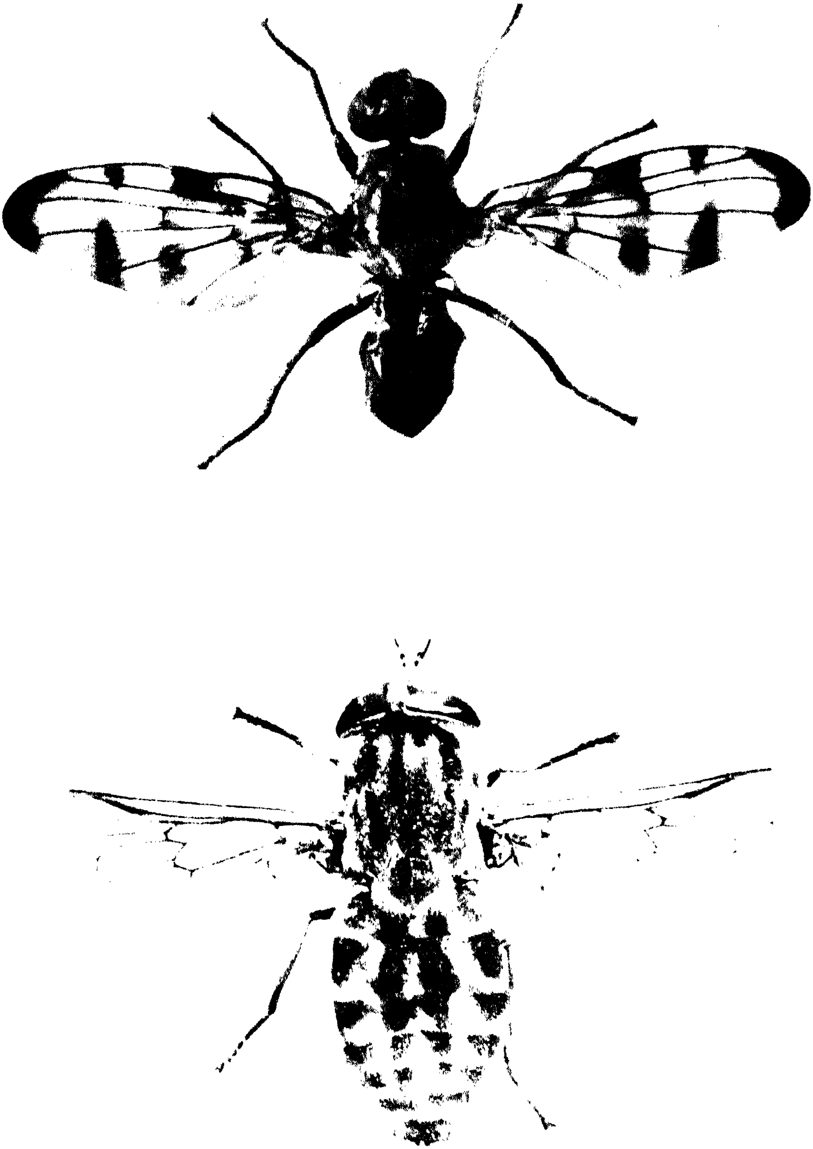


PLATE XXI. TWO EXAMPLES OF TRUE FLIES (*Diptera*)

A. Celery fly (*Philophylla heraclei* L.) ♀ (× 8)

B. Gad fly (*Tabanus autumnalis* L.) ♀ (× 4)

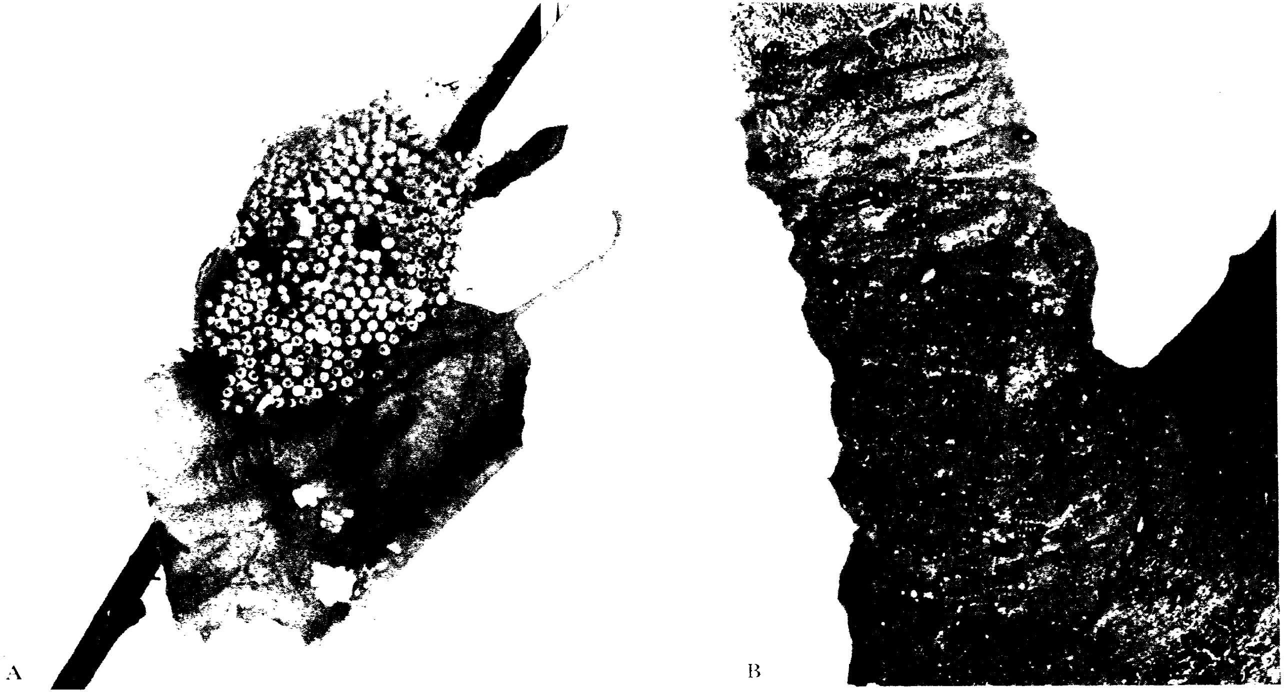


PLATE XXII. EXAMPLES OF INSECT EGGS

A. Cluster of eggs of vapourer moth (*Orgyia antiqua* L.) laid by the wingless female upon the cocoon from which she emerged (× 2)

B. Part of base of apple twig in winter, showing black shining eggs of aphids; narrow, pointed (light-coloured) eggs of apple sucker; and tiny spherical eggs of fruit tree red spider mite, in rows in the scars on the left at the junction of the twig with the branch (× 7) jointed legs. The head and thorax are united into a *cephalo-thorax* which has two pairs of antennæ.

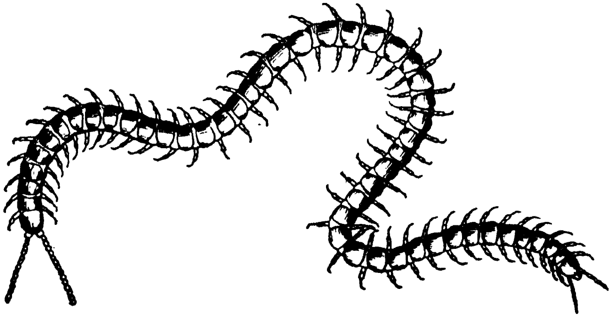


FIG. 73.—CENTIPEDE (*Geophilus*) : × 4.

2. Spiders, mites (Fig. 72), ticks and scorpions have 4 pairs of legs. The head and thorax are united to form a cephalo-thorax which has no antennæ.

3. Millipedes, centipedes (Fig. 73) and symphylids have a distinct head with one pair of antennæ. The body consists of many segments each with legs. Millipedes to some extent resemble caterpillars but have a greater number of body segments, most of which bear two pairs of legs. They have biting mouths with weak jaws or mandibles, and feed mainly on decaying organic matter. They are often found in crops already attacked by slugs and insects. Centipedes differ from millipedes in that they have only one pair of legs on each body segment and the first pair are developed into poison fangs. They are carnivorous and move rapidly through the soil, devouring small slugs, snails, insects and other creatures.

Symphylids are fragile white creatures about one-quarter of an inch long, with long, slender antennæ, twelve pairs of legs and a pair of tail-feelers. They usually abound in soil rich in organic matter and feed on soil organisms and on plant roots. They are often troublesome in market garden greenhouses where they damage roots of lettuce and tomatoes.

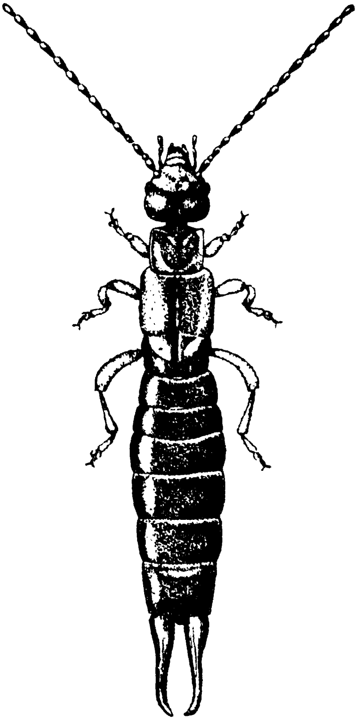


FIG. 74.—EARWIG ♀, : × 3.
Note the three main divisions of the body, and the presence of three pairs of legs on the thorax.

4. The **Hexapoda** or six-footed animals form the largest and most varied group of **Arthropoda.** They are generally called **Insecta,** or insects, because the body is divided into three distinct sections, namely head, thorax and abdomen. The head carries one pair of antennæ, the thorax carries three pairs of legs and, in winged insects, one or two pairs of wings, and the abdomen is without true (jointed) legs (Fig. 74).

THE FORM AND STRUCTURE OF INSECTS

The Head and Mouthparts. The head is thought to have developed from the union of several segments each of which carried a pair of limbs, and in the course of evolution the limbs have become antennæ and mouthparts. Insects have two kinds of eyes: compound or faceted eyes, and simple eyes or *ocelli.* In most insects there are three ocelli arranged in a triangle near the top of the head; these are missing in earwig (Fig. 75) but are seen in frit fly (Fig. 77). The compound eyes are often of a greenish or reddish colour, and may occupy most of the top and sides of the head. Insect mouthparts are complicated structures and two distinct types occur, the biting or mandibulate mouth and the piercing and sucking mouth.

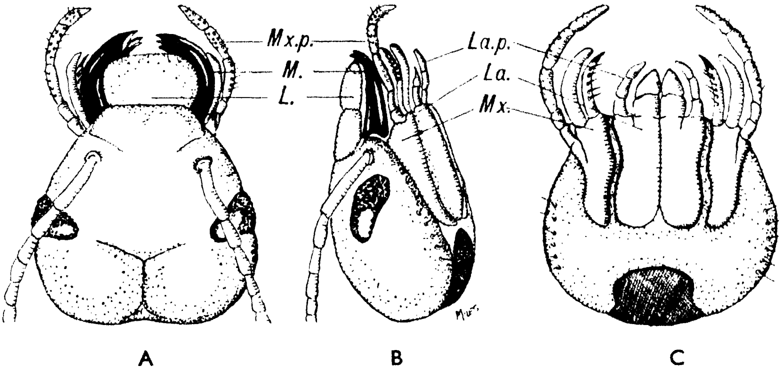


FIG. 75.—HEAD OF EARWIG : × 12.

A, head of earwig from above, showing L., labrum ; M., mandible ; Mx.p., palp of maxilla.
B, side view to show relationship of mouthparts.
C, head from below, showing La., labium ; Mx., maxilla (labrum and mandibles removed).

Mandibulate Mouthparts. In beetles, wasps, earwigs, grasshoppers and cockroaches the mouth structures conform to a more or less typical and easily recognisable pattern (Fig. 75). The mouth is closed on the upper side by a tough, horny flap, the *labrum* or upper lip. Beneath it are the mouthparts (Fig. 75) which consist of three pairs of jaws overlying one another and working in a horizontal plane: and the upper jaws or *mandibles*, the middle jaws or first pair of *maxillæ*, and a *labium* or lower lip formed by the fusion of the second, or lower, pair of maxillæ. The mandibles are thick and strong and generally consist of a single segment. They may be

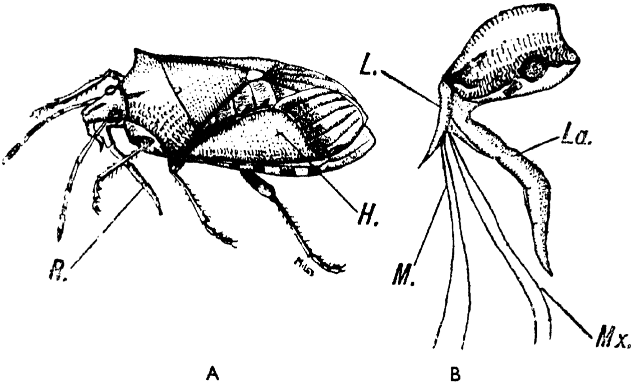


Fig. 76.—Shield Bug (*Acanthosoma*) : × 3½.

A, shield bug : R., rostrum ; H., hemi-elytra.
B, head enlarged to show L., labrum ; M., mandibular stylets ; Mx., maxillary stylets ; La., labium.

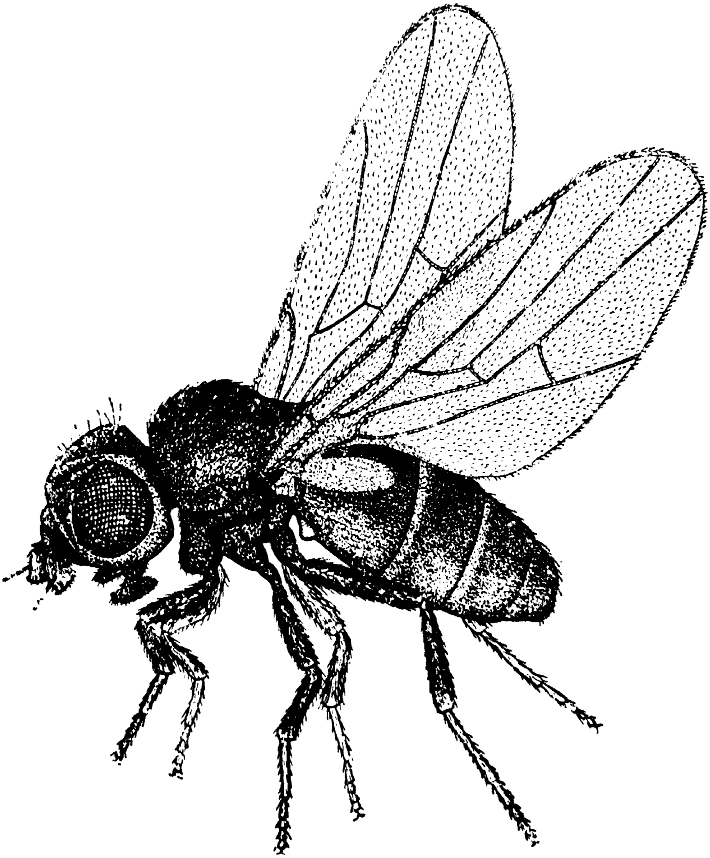


Fig. 77.—Frit Fly : × 30.

sickle-shaped as in carnivorous ground beetles (Carabidæ) and glow-worms (Lampyridæ), or broad and ridged or toothed for tearing and grinding plant tissue, as in caterpillars and wireworms. The middle pair of jaws, or first pair of maxillæ, are delicate complicated structures often fringed with spines and bearing a pair of mouth-feelers, the *maxillary palps*. The maxillæ assist in the mastication of food. The lower lip or labium consists of the second pair of maxillæ fused to form a single structure with a pair of feelers, the *labial palps*. It closes the mouth from below and may have attached to it the open end of the salivary duct. In caterpillars the salivary duct is highly developed and the labium is modified to form a *spinneret* from which saliva passes like a continuous thread of silk. The salivary strand of some moths, as for example *Lasiocampa* and the silk-worm moth (*Bombyx mori* L.), is used to make silk.

Sucking Mouthparts. In bees, flies, butterflies, mosquitoes, aphid and bugs (Fig. 76) the mouthparts have undergone much change of form and arrangement to enable the insects to feed on liquids. Houseflies and allied flies have a short broad sucking proboscis for lapping superficial liquid. The honey bee has a long sucking proboscis for gathering nectar and a pair of stout mandibles for removing wax or other obstruction. In butterflies and moths there is a long flexible proboscis which, when not in use, lies curled under the head. Mosquitoes, gadflies, bugs and aphids have mouthparts adapted for piercing the animal or plant host and sucking liquid from below the surface (Fig. 91).

The character of the mouthparts and the manner of feeding have greatly influenced the measures taken to check insect damage to crops and stock. Injurious insects with biting jaws devour leaves, stems and fruits, and may be killed by coating the food plants or bait with stomach poisons like lead arsenate and Paris green. They may also be killed with contact poisons like nicotine, rotenone (derris), DDT (dichlor-diphenyl-trichloroethane) and benzene hexachloride. Biting insects are not usually carriers of plant and animal diseases, and their presence in small numbers on established plants is generally of little importance. Injurious insects with piercing and sucking mouths are always a serious menace. Their feeding causes distortion and stunting of plants, and swelling and irritation in stock, and they transmit virus diseases in plants and fevers in man and animals. They draw food from below the surface and consequently are not affected by stomach poisons spread over their hosts. Contact or systemic insecticides must be used against sucking insects.

The Thorax and Limbs. The midbody or thorax occupies the region between the head and the hind body, but its junction with the hind body may be so complicated that it is difficult to see where one ends and the other begins. The thorax consists of three segments, the pro- (or fore) thorax, the meso- (or middle) thorax and the meta- (or hind) thorax. It carries the legs and wings, and is usually stout and strong in order to support the powerful wing and leg muscles which almost fill the interior. Each thoracic segment has a pair of legs, and when wings are present these are attached to the middle and hind thoracic segments.

The Legs. Insect legs have a common basic pattern of segments though the size and shape of the various segments show remarkable variation. They consist of five parts: coxa, trochanter, femur,

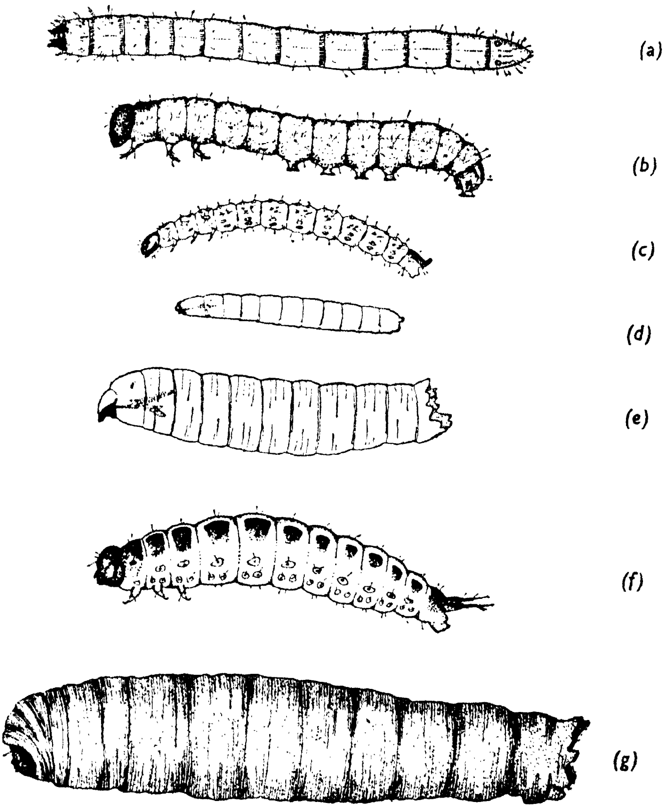


FIG. 78.—SOME INSECT LARVÆ.

(*a*) wireworm, grub of beetle (dorsal view) has 3 pairs of true legs, and a false foot on tail segment (*Agriotes*, Coleoptera) : × 5.

(*b*) caterpillar of moth with 3 pairs of true legs, false legs on segments 6, 7, 8, 9, 13. A grass stem-borer (*Apamea*, Lepidoptera) : × 4.

(*c*) flea beetle grub with 3 pairs of true legs, and false foot on the tail segment (*Psylliodes*, Coleoptera) : × 10.

(*d*) maggot of frit fly with reduced head, mouth hooks instead of mandibles, no legs (*Oscinis*, Diptera) : × 8.

(*e*) maggot of wheat bulb fly (*Hylemyia*, Diptera) : × 8.

(*f*) grub of wheat mud beetle with 3 pairs of true legs, and a false foot on tail segment (*Empleurus*, Coleoptera) : × 8.

(*g*) leatherjacket, maggot of daddy-long-legs or crane fly, with small head withdrawn into body, mandibles, no legs (*Tipula*, Diptera) : × 8.

tibia and tarsus. The *coxa* is a short, broad, flattened segment closely joined to the body. The *trochanter* is generally a small triangular strut-like segment at the articulation of coxa and femur. The *femur* or thigh is a long strong segment greatly enlarged for jumping in grasshoppers and flea beetles. The *tibia* is usually long and slender and often has characteristic spines and hairs. The *tarsus* consists of 1–5 small tarsal segments tipped with sensitive hairs, and a pair of tarsal claws.

The Wings. The number and character of the wings are used in the classification of insects. Butterflies (Lepidoptera) have two pairs of wings thickly clothed with scales. Ants, bees, wasps and sawflies (Hymenoptera) have two pairs of membranous wings, each with a stigma or small thickened area near the middle of the front edge. Beetles (Coleoptera) have a pair of leathery fore wings or *elytra* that form a protective cover for the membranous hind wings. Some of the plant bugs (Hemiptera or Rhynchota) have *hemi-elytra* : that is the fore wings are thickened at the base and membranous at the extremities, and the hind wings (Fig. 76) are membranous. The flies (Fig. 89) (Diptera) have a pair of membranous fore wings and a pair of knob-like *halteres* or balancers which are thought to be degenerate hind wings.

The Abdomen. The abdomen or hind body of an insect consists of as many as 10 rings or segments, some of which may be telescoped within the body. In adult insects the abdomen is legless, but caterpillars of butterflies, moths and sawflies have several pairs of abdominal false feet or *pseudopods* (Fig. 78, *b*). In some insects the tip of the abdomen bears a pair of tail-feelers or *cerci* (Fig. 78, *f*). The bristle-tails (silver-fish and other Thysanura) have a pair of long slender cerci, sometimes also a long median tail, the *telson*. In

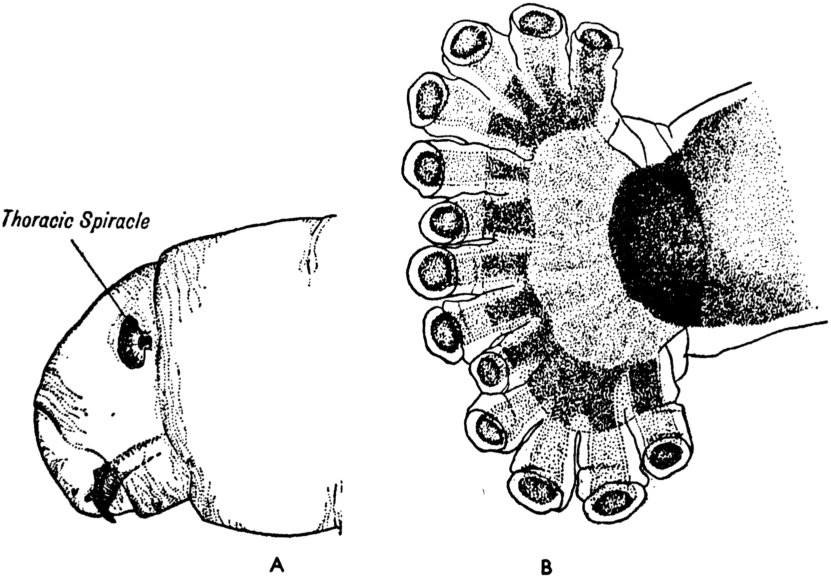


FIG. 79.—STRUCTURE OF A SPIRACLE.
A, head of cabbage root fly maggot, showing mouth hooks and thoracic spiracle : × 16. B, spiracle much enlarged.

earwigs the cerci are conspicuous pincers (Fig. 74). The abdomen contains the reproductive system, and the egg-laying mechanism which projects from the tip of the body in grasshoppers, cockroaches, ichneumon wasps and sawflies.

The Respiratory System. Most insects breathe by means of a system of air-tubes or *tracheæ*, whose branches extend throughout the body and limbs. The main trunk air-tubes lie internally on each side of the body and air enters from pores or *spiracles* in the sides. In most insects spiracles occur on the mid and hind thoracic segments and on the first eight abdominal segments, but in the maggots of blow fly, frit fly, cabbage root fly (Fig. 79) and their allies there are only two pairs of spiracles, one pair in the fore thorax close to the head and another at the tip of the tail. The air tubes are strengthened and kept open by a spiral thickening, and the inflow of air is regulated by the opening and closing of the spiracles. Much of the carbon dioxide passes out of the body through the skin.

The Exoskeleton. The form and character of insects depends on the outer case or *exoskeleton* which encloses the body. It is a continuous covering or *integument* with thickened horny plates or *sclerites* over the segments, and with thin intersegmental membrane folded under the sclerites. The horny sclerites give shape and protection to limbs and vital organs, and the membrane between the sclerites gives the insect the flexibility necessary for movement and permits some expansion of the body. The skin of insects is largely composed of *chitin*, a complex substance related chemically to the cartilage of vertebrate animals. Chitin is insoluble in water, ether and other organic solvents, and in dilute acids. It may be softened in dilute and concentrated alkalis.

GROWTH AND CHANGE OF FORM IN INSECTS

Most insects hatch from eggs (Plates XIX and XX). Insect eggs show remarkable variation in colour, form and texture, from the tall smooth elliptical bright yellow eggs of ladybird beetles to the flat greenish or drab scale-like eggs of many small moths. The period of incubation also varies from about three days for the summer eggs of cabbage root fly to several months for the overwintering eggs of the vapourer moth (*Orgyia antiqua* L.) and aphides.

The Moult or Ecdysis. Insects begin to feed soon after they hatch but their tough inelastic skin will not permit of a gradual increase in size. As feeding takes place the old skin becomes distended and finally splits and is shed. The moult, or *ecdysis*, is immediately followed by a considerable expansion of all parts of the body. When an insect is about to moult it rests until the contents of the alimentary canal are absorbed or voided. Moisture is secreted between the old and new skins so that the two are completely separated, and as a result of strains and pressure the old skin ruptures, usually near the head. The insect then withdraws its head and gradually pushes the old skin backwards off the body. Attached to the old skin are the lining of the alimentary canal and main air-tubes (spiracles and tracheae), and the hard outer shell of jaws, feelers, spines, legs and claws. The insect rests until the new skin toughens and assumes its normal colour. Before the new skin finally hardens and oxidises considerable expansion takes place, and many insects are approximately one-quarter larger after the moult than they were before. The number of moults varies in different insects and in the sexes, many caterpillars having 6–7 moults while maggots of flies may reach maturity after 2–3 moults.

Metamorphosis. Many insects undergo great change of form in the course of growth while others retain the same form through life. Simple insects like bristle-tails (Thysanura) and spring-tails (Collembola) (Fig. 80) emerge from eggs in a form similar to that of the adults. They grow larger at each moult but undergo no change of form or metamorphosis.

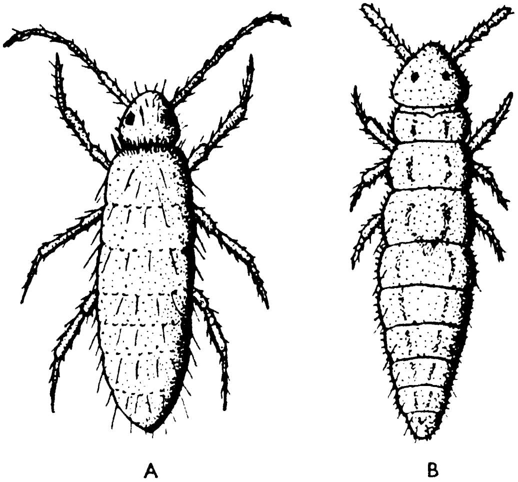


FIG. 80.—SPRINGTAILS.

A, longhorned springtail (*Tomocerus*): × 22.
B, shorthorned springtail (*Hypogastrura*) : × 30.

Examples of the Apterygota, insects wingless at all stages, with no change of form from hatching to maturity. From *Insect Pests of Glasshouse Crops*, by H. W. and M. Miles (Crosby Lockwood).

Insects which retain the same form throughout life are called *AMETABOLA* (without metamorphosis) ; they are also known as *APTERYGOTA* (without wings) because the adults are wingless.

A second group of insects undergoes a partial change of form in the course of development : they are known as *HEMIMETABOLA*. Grasshoppers, earwigs, cockroaches, dragonflies, aphides, thrips and plant bugs are hemimetabolous. The young emerge from the eggs in a form resembling that of the adults. Mouthparts, antennæ, legs and general body-shape are similar in young and adults but the young are wingless and are known as *nymphs*. Wings develop externally in pouches on the back and at each moult the wing pouches grow larger. At the last moult the pouches are shed with the skin and the wings assume the size, shape and colour of adult wings. Insects whose wings develop externally in pouches or sacs on the back are also known as *EXOPTERYGOTA* (external wings) (Fig. 81).

The third main insect group is the *HOLOMETABOLA*, insects that undergo complete transformation during their development. This group includes beetles, ants, bees, wasps, sawflies, flies, moths, butterflies, caddis flies, weevils and lace wings. Beetles begin their active lives as grubs with three pairs of legs (Fig. 78, *c* and *f*) ; weevil grubs and the grubs of bees and wasps are legless. Butterflies, moths, caddis flies and sawflies pass the first part of their active life as caterpillars (Fig. 78, *b*) feeding on leaves, stems, roots, fruits and seeds or, in the case of caddis flies, mostly on small aquatic animals. The immature stages of flies are legless maggots, worm-like in the stilleto fly (*Thereva*), and stout and wrinkled in the crane fly and wheat bulb fly (Fig. 78, *e* and *g*).

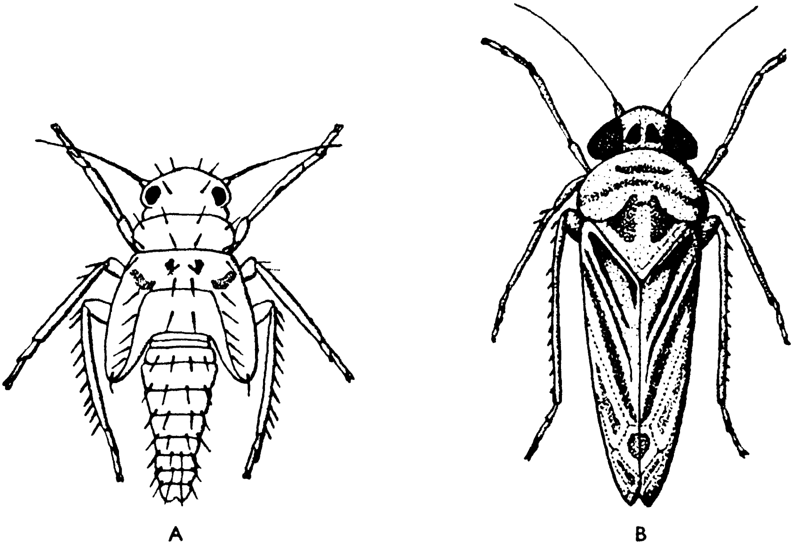


FIG. 81.—NYMPH AND ADULT OF LEAF HOPPER (*Erythroneura*).

A, nymph with well-grown wing-buds.
B, adult with fully developed wings: × 18.

An example of Exopterygota, insects with external wing development. From *Insect Pests of Glasshouse Crops*, by H. W. and M. Miles (Crosby Lockwood).

Grubs, caterpillars and maggots are still in an embryonic stage. The eggs from which they hatch contain insufficient food to permit them to complete their development and they emerge as *larvæ* and spend their time feeding. When a sufficient store of food has been accumulated adult tissue and limbs begin to grow within the larval body and when the last larval skin is shed the insects become inactive chrysalids or *pupæ*. During the pupal stage the larval body is broken down and remade into adult tissue, and adult limbs and organs acquire their characteristic form. When the transformation of larva into adult insect is complete the pupal case is shed and the adult or *imago* is revealed. Insects that pass through the larval and pupal stages before reaching maturity are classed as *ENDOPTERYGOTA* (internal wings) because early wing growth takes place within the larval body.

The chief characters of the three groups of insects can be summarised as follows :

AMETABOLA OR APTERYGOTA. Young resemble adults in form and mode of life ; no marked change or transformation occurs during growth, and adults are wingless. (Silver-fish, bristle-tails, spring-tails.)

HEMIMETABOLA OR EXOPTERYGOTA. Young resemble adults in form and, except in dragonflies and mayflies, have a similar mode of life. Wings develop externally in pouches on the back (Fig. 84). There is no pupal stage and insects pass immediately from nymph to adult. (Cockroaches, earwigs, grasshoppers, dragonflies, mayflies, aphides, thrips, bugs.)

HOLOMETABOLA OR ENDOPTERYGOTA. Insects of this group undergo complete transformation. There is a larval stage (as caterpillar, grub or maggot) concerned wholly with feeding, a resting stage as a pupa or chrysalid (Fig. 87) which is concerned with internal development, and an adult or imaginal stage concerned mainly with reproduction. Adults are winged and wing development takes place inside the body. (Butterflies, moths, beetles, weevils, ants, bees, wasps and flies.)

IMPORTANT ORDERS OF INSECTS

The main insect groups just described are divided into twenty-three Orders, ten of which are of interest and importance in agriculture and horticulture.

APTERYGOTA

Thysanura (Bristle-tails, Silver-fish) are slender active insect about ½ in. long, with the body soft and covered with scales and having at the tip two or three long cerci. They are wingless and have no metamorphosis, and are thought to resemble the ancestral type from which all insects have developed. Silver-fish (*Lepisma saccharina* L.) are common in old farmhouses where they feed on dust and dirt about kitchens and larders and on the paste of wallpaper and of books.

Collembola (Spring-tails) (Fig. 80) are tiny wingless insects some of which have a forked tail-structure, the *furcula*, held in a catch or *hamula* on the underside of the body. The release of the furcula from the hamula propels the insects forward and earns them the name " spring-tails ". There are two types of spring-tails : those with the body cylindrical and elongate and the segmentation well defined (*Anurida*, *Tomocerus*), and those with a rather globular body with obscure segmentation (Sminthuridæ). The former are often found about the soil and under stones, the latter about foliage and among seedlings. Spring-tails have weak mandibles and feed on soft plant tissue. They frequent decaying organic matter, mushrooms and other fungi, and sometimes attack seedlings and sickly plants. They are often found in large numbers on swedes and mangolds damaged by hoeing or broken off by " strangles ".

EXOPTERYGOTA

Orthoptera (Cockroaches, Crickets, Grasshoppers and Locusts) have strong biting mouths, two pairs of straight stiff wings, and legs adapted for running (cockroaches) and jumping (grasshoppers, bush-crickets and locusts). The fore-wings or *tegmina* are long, narrow and thickened to form a leathery cover for the broad membranous hind wings that fold fan-wise when at rest. Metamorphosis is incomplete and wings develop externally. Cockroaches and crickets are omnivorous and occur in boiler-houses and in warm food stores and preparation-rooms. Bush-crickets are largely carnivorous and devour other insects. Grasshoppers and locusts are plant-feeders and in some parts of the world they occur in devastating swarms.

Dermaptera (Earwigs) (Fig. 74) are closely related to Orthoptera but have short leathery fore-wings and semi-circular membranous hind-wings that fold into a double fan beneath the forewings. The cerci or forceps are sickle-shaped in males and straight in females. Earwigs feed on decaying organic matter. They are mainly scavengers but in late summer and autumn they devour leaves and flowers of cultivated plants. Earwigs hibernate as adults in soil, in hollow stems and under bark. Eggs are laid in clusters in the soil in spring and the female tends her eggs during the incubation period and looks after the young for a short time after they hatch.

Hemiptera or Rhynchota (Bugs, Aphids, Scale insects, Mealy Bugs and White Flies) have mouthparts adapted for piercing and sucking liquid from their hosts (Fig. 76). The lower lip is modified into a beak or *rostrum* and the two pairs of jaws, the mandibles and maxillæ, are modified into slender piercing stylets. Metamorphosis is incomplete and the wings develop externally. There are usually two pairs of wings and the character of the first pair is used to separate Hemiptera into two sub-orders, Heteroptera and Homoptera.

HETEROPTERA (Plant bugs, Shield-bugs, Capsids) (Plate XXIX) have the fore-wings modified into *hemi-elytra*, that is the base is tough and leathery and the tip is membranous. The hind-wings are entirely membranous and both pairs fold closely over the body. The head is usually small and triangular, and the beak arises from its front margin. The shield bugs (*Pentatomidæ*) (Fig. 76) have long 5-segmented antennæ and shield-shaped bodies and when disturbed or handled they give off an unpleasant odour from large pores on the underside of the thorax. Many British shield bugs are predaceous. Capsid bugs (*Lygus* and *Plesiocoris* spp.) are slender, oval and greenish. They are common about herbaceous plants, trees and bushes and feed by puncturing young stems and leaves and sucking the sap.

Their feeding causes such severe distortion that they rank as major pests of fruit trees and bushes, strawberries, potatoes and many flower crops.

HOMOPTERA (Aphids, Frog-hoppers, Leaf-hoppers) have wings that are entirely membranous or uniformly thickened. The beak appears to arise from the hind margin of the head and point backwards. The leaf-hoppers (Jassidæ) and frog-hoppers (Cercopidæ) have the fore-wing slightly thickened, and the antenna short and tipped with a long slender bristle. Leaf-hoppers are common about foliage and jump when disturbed, and their feeding-sites show as small pale or bleached spots on the leaves. The nymphs of frog-hoppers cover themselves with froth and are called " cuckoo-spit " insects.

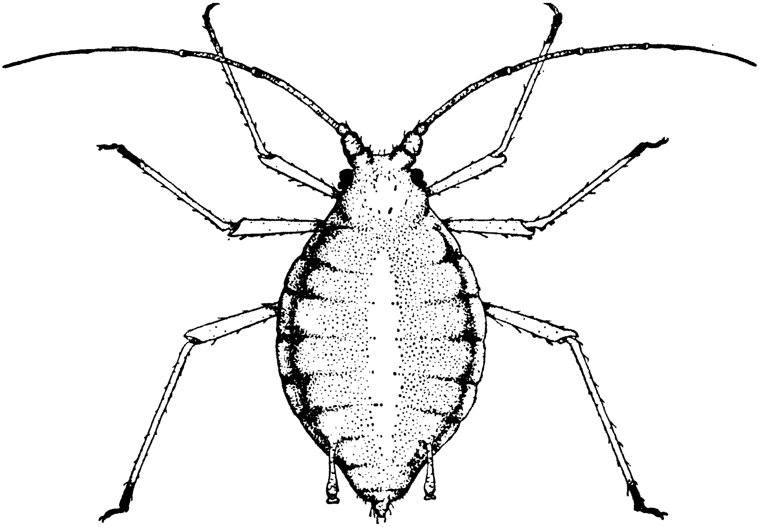


FIG. 82.—WINGLESS FEMALE OF PEACH-POTATO APHIS (*Myzus persicæ*) : × 22.
From *Insect Pests of Glasshouse Crops*, by H. W. & M. Miles (Crosby Lockwood)

Aphids or plant-lice (Aphididæ) have long slender antennæ and a pair of tubular cornicles on the back near the tip of the body (Fig. 82). Winged aphids have two pairs of membranous wings; the fore-wings are larger than the hind-wings and have a characteristic arrangement of veins. The typical annual life cycle among aphids includes overwintering eggs ; wingless females of the spring generation that give rise to colonies of wingless aphids on the spring host ; winged summer migrants that fly to the summer host and start the summer colonies of wingless aphids ; and winged autumn migrants that return to the winter host and give rise to males and females that together produce overwintering eggs. During spring and summer reproduction is parthenogenetic, that is, without the act of mating, and aphis colonies are produced rapidly in this way. The mealy cabbage aphis (Plate XXIV) (*Brevicoryne brassicæ* L.) passes the winter in the egg stage on brussels sprouts, kale and cabbage, but in mild seasons parthenogenetic reproduction may continue throughout the winter. The black aphis of beans, sugar beet and mangolds (*Aphis fabæ*) overwinters in the egg stage on spindle (*Euonymus*), a common hedgerow shrub in many districts, and the number of eggs found on spindle in winter enables observers to forecast the intensity of attack by black fly on susceptible crops in the following season. Aphids are important carriers or vectors of virus diseases in plants. The control of mosaic and leaf-curl diseases of potatoes is largely a matter of preventing aphid infestation of the crop. The method selected is one of prevention rather than cure, stocks of seed potatoes being usually grown in districts where aphids are absent or rare. Protective spraying of seed crops against aphids is a recent development.

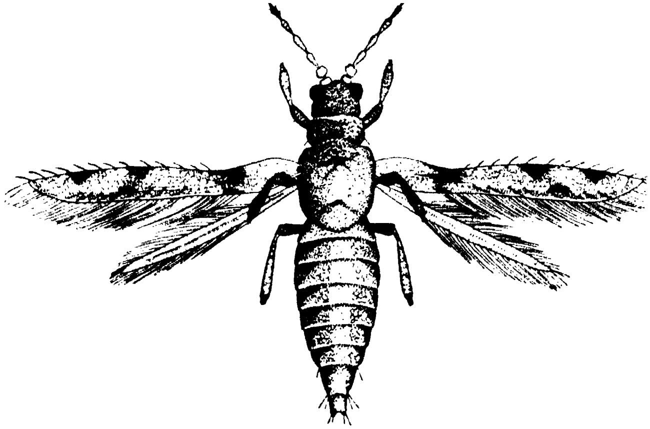


FIG. 83.—THRIPS (*Parthenothrips dracenæ*).
From *Insect Pests of Glasshouse Crops*, by H. W. & M. Miles (Crosby Lockwood).

Thysanoptera (Thrips) are tiny slender insects with a rather triangular head and short stout antennæ. The mouthparts are peculiar in that one mandible is modified into a piercing stylet, and the insect sucks sap after piercing the tissue. Thrips have two pairs of narrow wings fringed with long hairs (Fig. 83). Metamorphosis is incomplete, but in some species the last nymphal stage is quiescent in the surface soil for some time before the insect emerges as an adult. Thrips are common about crops, and at harvest they settle on faces and arms of the workers. One species carries Spotted Wilt, a virus disease of glasshouse plants; another species occasionally attacks seedling Brassicas and may infest leeks and onions on market gardens.

ENDOPTERYGOTA

Lepidoptera (Butterflies and Moths) have two pairs of wings thickly covered with coloured scales arranged in characteristic patterns. The antennæ are long and in males they are often conspicuously plumed. The second pair of jaws (maxillæ) form a long proboscis for sucking nectar and capable of being coiled beneath the head when not in use. Lepidoptera undergo complete metamorphosis, passing through larval and pupal stages before reaching maturity. Larvæ of Lepidoptera are caterpillars with stout biting mouthparts, three pairs of thoracic legs and usually with five pairs of false legs (prolegs or pseudopods), tipped with small hooks or crotchets on abdominal segments 3, 4, 5, 6 and 10. Caterpillars of winter moths (Geometridæ) have false legs only on the sixth and last abdominal segments and progress in a looping manner that has earned them the name of " loopers ".

Most caterpillars are plant feeders but their habits, form and colour show great differences. Caterpillars of tortoiseshell, peacock and large cabbage white (Plate XXVII) butterflies and lackey and small ermine moths feed in colonies often in a web of silk. Many caterpillars are green and inconspicuous among the foliage while others like those of the peppered moth (*Biston betularius* L.) have a twig-like appearance. Caterpillars of tortrix moths make a feeding shelter by spinning together the tips of shoots ; others like the lilac leaf miner (*Gracillaria syringella* F.) feed between the upper and lower leaf surfaces of privet and lilac, and many, such as the leopard moth, goat moth, and apple pith moth, feed in the woody interior of branches and twigs of trees. The woolly bear caterpillars of the garden tiger moth are protected by their long irritating hairs, and caterpillars of puss moth (*Cerura vinula* L.) and the lobster moth (*Stauropus fagi* L.) by their menacing appearance.

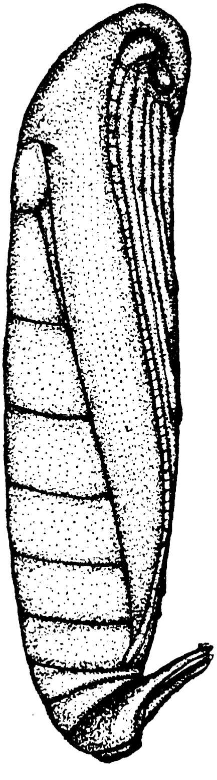


FIG. 84.—CHRYSALIS OF APPLE PITH MOTH (*Blastodacna*) showing outlines of developing adult : × 16.

Chrysalids or pupæ of butterflies tend to be spindle-shaped with the wings projecting on the underside of the body, and those of moths are elongate oval with the wings folded close to the sides (Fig. 84). Chrysalids of butterflies are often suspended by the tail and supported by a girdle round the thorax. Caterpillars of the drinker moth and its relatives (Lasiocampidæ) construct large silken cocoons and many caterpillars enter the soil and make earthen cells.

Many common pests belong to the order Lepidoptera. Swift moths (Hepialidæ) have very short antennæ and fly rapidly at dusk during May and June. The whitish caterpillars live in the earth and feed at the roots of grass and in the tap-roots of grassland herbs, and are occasionally injurious in strawberry plantations and market gardens. Clearwing moths (Sesiidæ) resemble bees and wasps in appearance ; the caterpillars live in the woody twigs and branches of currants, fruit trees, willows and poplars. The large caterpillars of hawk moths (Sphingidæ) feed on foliage, those of the death's head (*Acherontia atropos* L.) devouring potato haulms and those of the eyed hawk (*Smerinthus ocellatus* L.) devouring the leaves of fruit trees. The looper caterpillars of the large family Geometridæ feed on the leaves of forest trees, fruit trees and ornamental trees and shrubs. Those of the winter moth (*Cheimatobia brumata* L.) and its allies are of special interest to fruit-growers who use grease-bands, DDT and other sprays and egg-killing winter washes against them.

The owlet moths (Noctuidæ) which fly at night and shelter in herbage during the day include the large yellow underwing (*Triphaena pronuba* L.), turnip moth (*A. segetum* Schiff.), heart and dart (*A. exclamationis* L.), antler moth (*Charæas graminis* L.), light arches (*Xylophasia lithoxylea* F.), tomato moth (*Mamestra oleracea* L.), and cabbage moth (*M. brassicæ* L.). Caterpillars of some of these moths are cutworms and surface caterpillars. They shelter in the soil by day and feed by night at or near ground level. They then pupate just below the soil surface and the chrysalids are chestnut brown, smooth and polished.

Small injurious moths (Tineina) include the diamond-back (*Plutella maculipennis* Curt.) which feeds on cultivated Brassicas ; the small ermine (*Yponomeuta padella* L.) whose caterpillars feed in colonies under webs or tents among the leaves of apples; the house moths (*Borkhausenia* and *Endrosis*) living on feeding stuffs in granaries. Caterpillars of the tortrix moths (Tortricidæ) generally live concealed in rolled leaves or in the tips of shoots. The oak leaf-roller (*Tortrix viridana* L.) sometimes defoliates oak forests, and apple tortrix (*T. podana* Sc.) devours leaves and damages fruit of apple and other fruit trees. Caterpillars of some tortrix moths are seed-feeders. Codling moth caterpillars (*Cydia pomonella* L.), notorious the world over, tunnel into apples and feed on the seeds ; and those of the pea moth (*C. nigricana* F.) feed on peas within the pods. Amongst the butterflies the cabbage whites (*Pieris brassicae* L., *P. rapae* L., *P. napi* L.) are troublesome on Brassica crops.

Coleoptera (Beetles and Weevils) are recognised by the hard or leathery fore-wings or elytra that meet in a straight line along the middle of the back, and usually cover the abdomen (Plate XIX). The hind-wings are membranous and when not in use are folded under the elytra. The legs are either long, for running, in ground beetles (Carabidae) ; broad and stout, for digging, in dung beetles (*Aphodius*); or modified to form swimming paddles in whirligig beetles (*Gyrinus*). The antennæ are long and slender in long-horn beetles (Longicornia); clubbed in burying beetles (*Necrophorus*) ; elbowed in the weevils ; and with a series of leaf-like segments or *lamellæ* in the cockchafer (*Melolontha vulgaris* L.). Beetles and weevils have biting mouths with well-developed mandibles, very large and antler-like in the male stag-beetle (*Lucanus cervus* L.), and sharp and sickle-shaped in tiger beetles (*Cicindela*).

Beetles and weevils undergo complete metamorphosis. Beetle grubs vary greatly in size and shape from the slender wireworms (*Agriotes*) (Plate XIX) to the large fleshy grubs of cockchafer and dor beetle (*Geotrupes*) but all have well-developed heads and three pairs of true legs on the thoracic segments. The grubs of weevils are wrinkled, fleshy and without legs (Fig. 86). Pupation takes place in the soil or in the feeding-sites. The pupæ are enclosed in a thin membrane with the limbs free.

Mode of life and habits show great variety among beetles. Ground beetles and their grubs are active carnivorous insects which prey upon slugs and other insects and are therefore beneficial. Ladybird beetles (Coccinellidæ) and their grubs feed on aphides. Rove beetles (Staphylinidæ) are readily recognised by the short elytra that cover only about a third of the body and by the habit of turning the tip of the body upwards in a menacing fashion. Both adults and grubs are carnivorous on soil creatures, small rove beetles (*Aleochara*) being parasitic on maggots and pupæ of cabbage root fly and its allies. Chafer beetles (*Melolontha*, *Amphimallus*, *Phyllopertha*) feed on the leaves and blossoms of fruit trees and shrubs and the grubs feed on the roots of grass, shrubs and fruit trees and bushes. Click beetles (Plate XIX) are elongate oval, and when placed on their backs they aright themselves by springing upwards with a sharp clicking sound. The turnip flea beetles (Plate XXVII), mustard beetles and willow beetles feed on foliage. They belong to a large group of beetles, the Phytophaga, and have the head directed downwards, long slender antennæ and shining greenish, bluish and bronze elytra. The Colorado beetle (*Leptinotarsa decemlineata* Say.) which feeds on potato haulm also belongs to this group. The wood-boring beetles (*Anobium* and *Lyctus*) are major pests of timber ; the longhorn beetles (Longicornia) are also wood-borers, and the typographer beetles (Scolytidæ) are bark-borers whose feeding-tunnels appear as curious engravings on fencing-posts and rails after the bark has been removed.

Weevils (Rhynchophora) are beetles with a long snout and elbowed antennæ clubbed at the tip (Plate XXVII). Pea and bean weevils (*Sitona*) have short stout beaks and feed on the leaves of peas and beans. The blossom weevils of the apple and strawberry (*Anthonomus*) have a slender beak of medium length with which they bite a hole in the blossom bud and deposit an egg in the hole. The nut weevils (*Balaninus*) have slender gracefully curved beaks, longer than the body. Grain weevils (*Calandra*) and a large number of associated beetles (*Ptinus*, *Niptus*, *Dermestes* and *Sitodrepa*) feed or grain and other stored products.

Hymenoptera (Bees, Wasps, Ants, Ichneumon wasps (Plate XXIII) and Sawflies) have two pairs of iridescent membranous wings. The antennæ are usually long and conspicuous and may be elbowed, clubbed, simple or branched. Mandibles are present but in some groups the maxillæ and labium are modified to form a sucking

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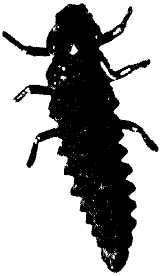

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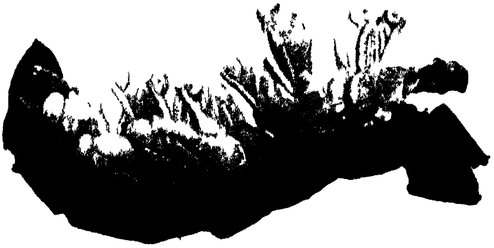

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PLATE XXIII. BENEFICIAL INSECTS

1, Ichneumon wasps (*Hymenoptera*) parasitic on small caterpillars, e.g. diamond back moth (female with long ovipositor) above, male below (× 5); 2, the ladybird grub (*Coleoptera*) is a predator; it devours aphids (× 5); 3, chrysalids of a parasitic wasp (*Paracodrus apterogynus* Hal.) emerging from the dead body of a wireworm in which they have developed (× 8); 4, maggot of hover fly (*Lasiopticus pyrastri* L.) (*Diptera*) feeding on an aphis colony (× 2)

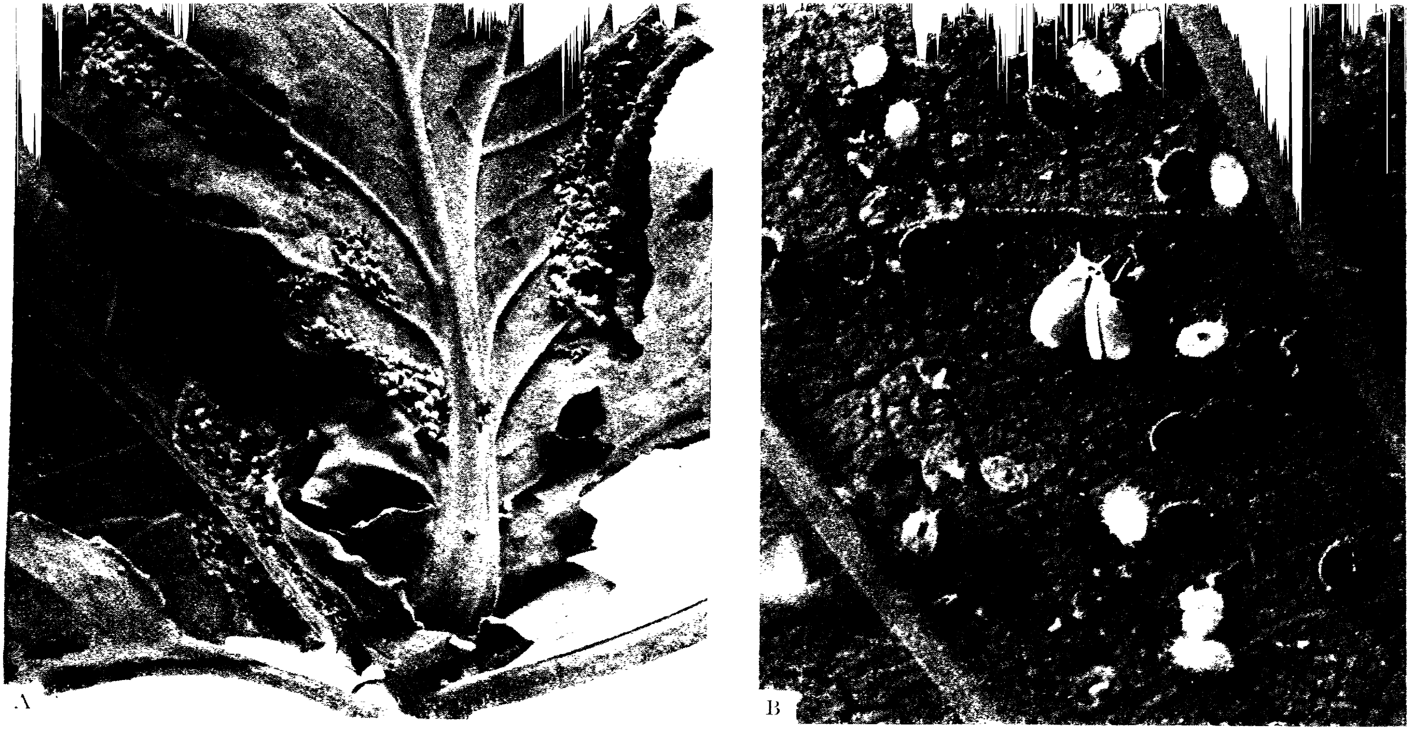


PLATE XXIV. EXAMPLES OF SUCKING INSECTS

A. Mealy cabbage aphis, developing colonies on young cabbage (nat. size)

B. Greenhouse white fly on the back of a tomato leaf; the white scales are the immature nymphs. The black scales have been destroyed by, and now contain, the chalcid parasite *Encarsia formosa* Gahan. (× 10)

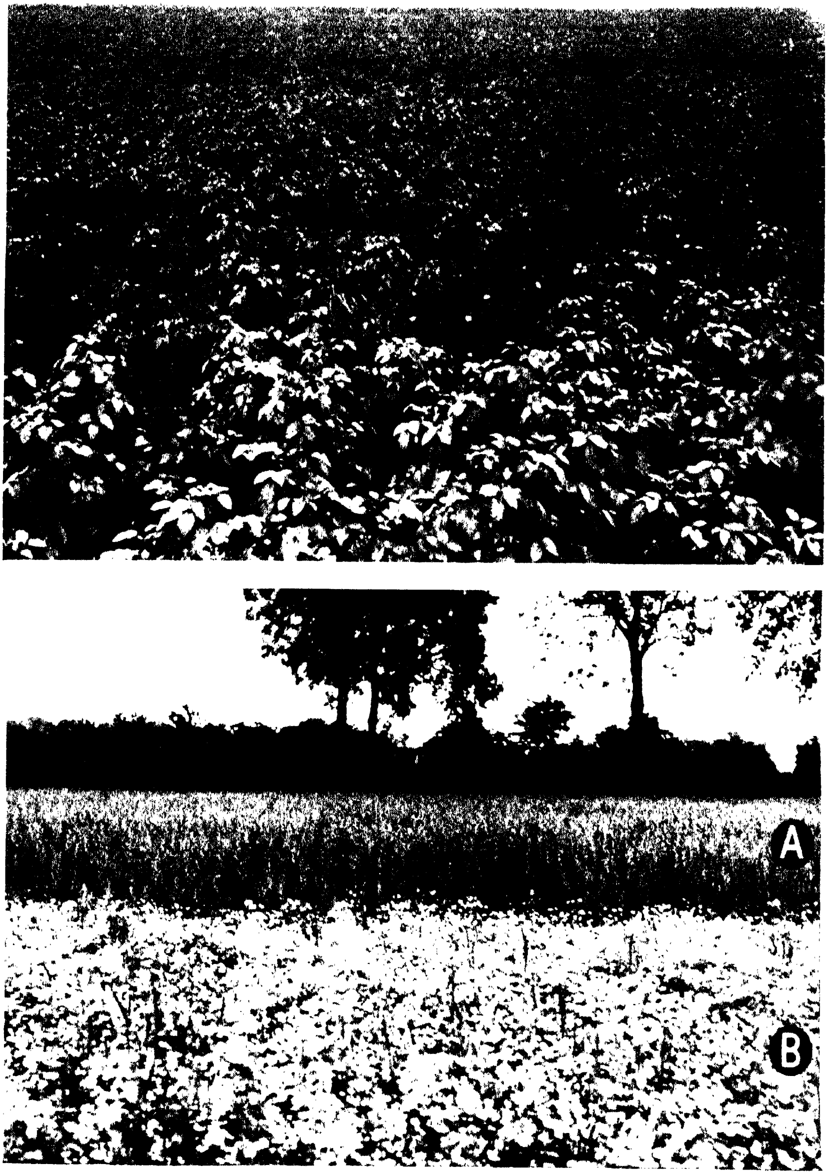


PLATE XXV. EELWORM DAMAGE

Above: Typical appearance of a potato crop infested with potato root eelworm (*Heterodora rostochiensis* Woll.)

Below: Reduction in oat crop due to cereal root eelworm (*H. major Schmidt*). The crop at A is the second oat crop in 5 years. At B, the land has carried 3 oat crops in 5 years, the rotation being oats : roots ; oats : roots : oats.

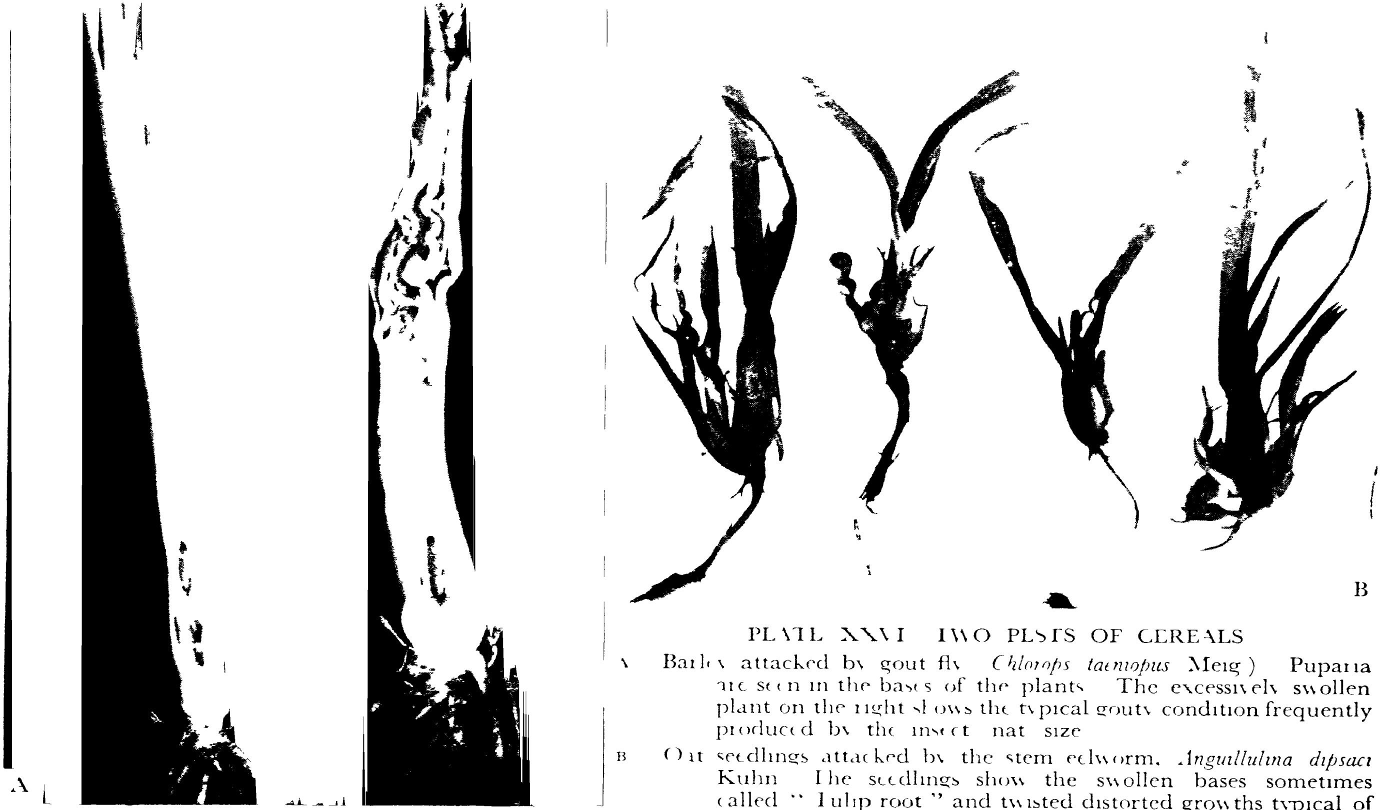
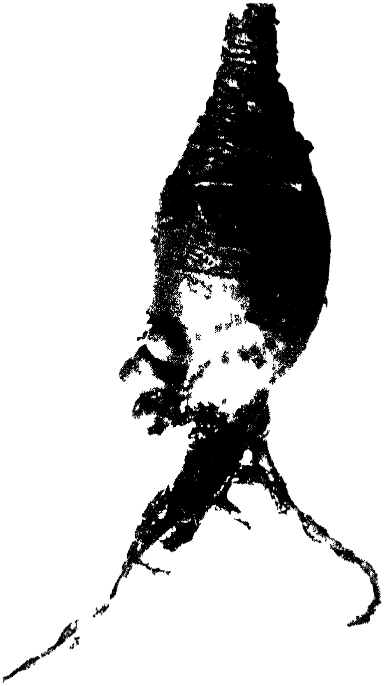


PLATE XXVI TWO PESTS OF CEREALS

A Barley attacked by gout fly (*Chlorops taeniopus* Meig.) Puparia are seen in the bases of the plants. The excessively swollen plant on the right shows the typical gouty condition frequently produced by the insect (nat. size)

B Oat seedlings attacked by the stem eelworm, *Anguillulina dipsaci* Kuhn. The seedlings show the swollen bases sometimes called "Tulip root" and twisted distorted growths typical of eelworm infestation (nat. size)



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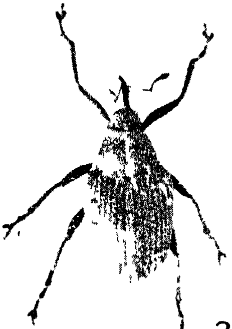
1. Attack by turnip gall weevil on swede. The galls on the left contain the grubs. Similar galls also occur on cabbage, cauliflower and other market garden brassicas. (nat. size)



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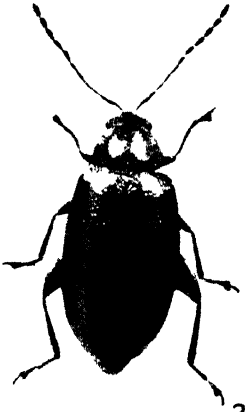

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PLATE XXXVII. PESTS OF BRASSICA CROPS

2. Turnip gall weevil (*Ceutorhynchus pleurostigma* Marsh.) adult (× 10)

3. Turnip flea beetle (*Phyllotreta nemorum* L.) adult (× 10)

4. Swedes damaged by caterpillar of cabbage white butterfly (*Pieris brassicae* L.)

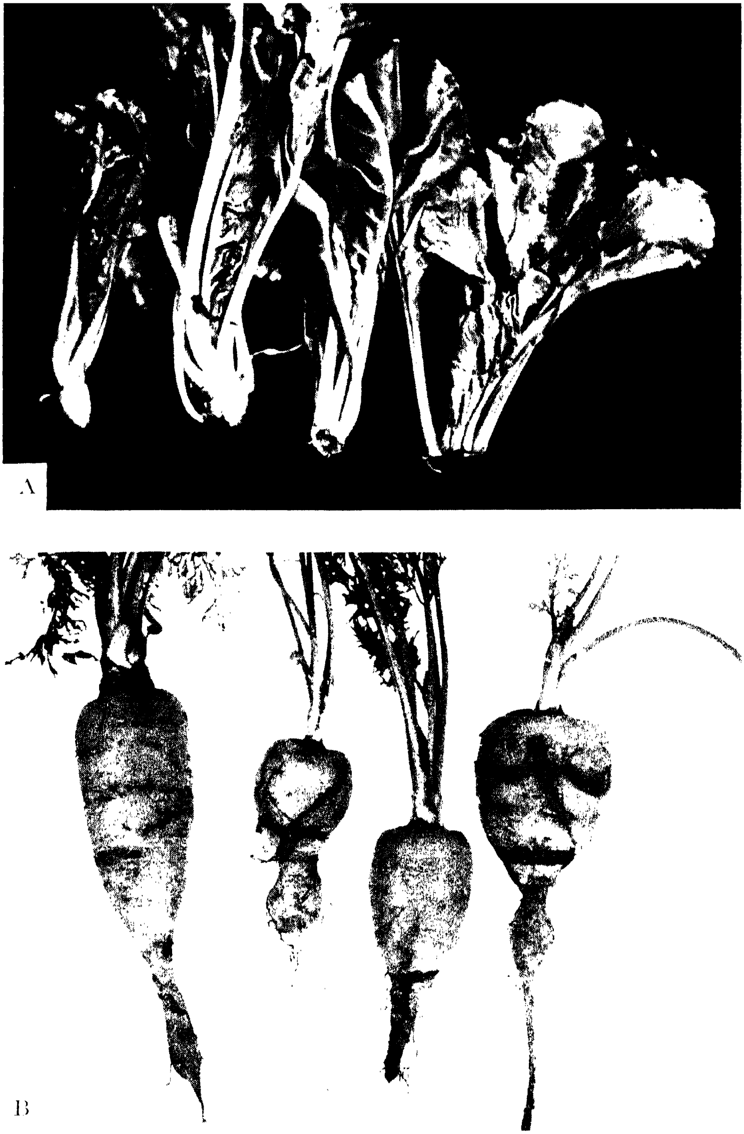
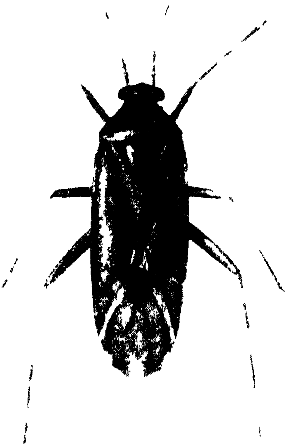
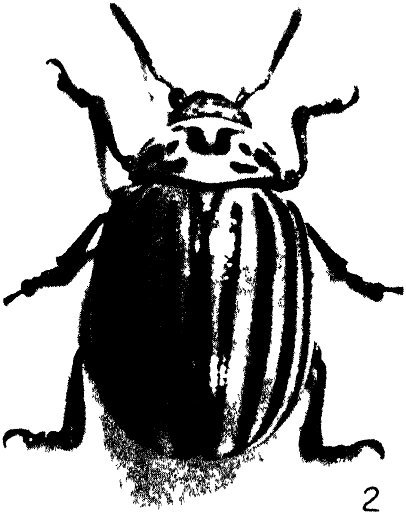


PLATE XXVIII. PESTS OF ROOT CROPS

A. On left, two sugar beet plants showing the condition known as strangles; on right, two plants damaged by rabbits

B. Attack by carrot fly (*Psila rosæ* F.) Note that the maggots have attacked the tips and the sides of the roots. Growth and normal development have been severely checked and the roots are unfit for market (nat. size)





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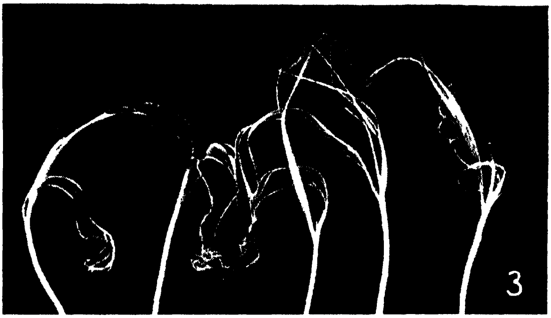

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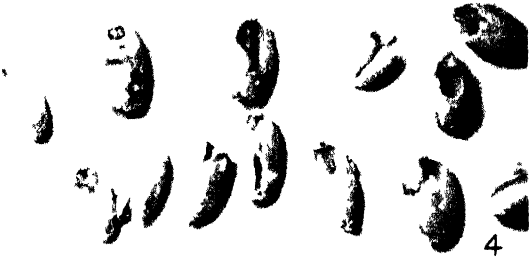

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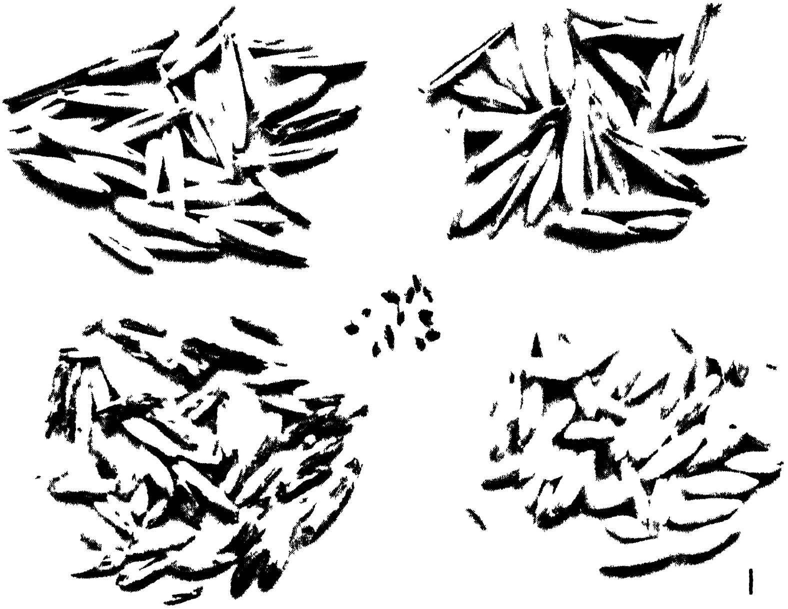
PLATE XXIX SOME PLANT PESTS

1 Capsid Bug (*Plesiocoris rugicollis* Fall.) (× 8)

2 Colorado Beetle (*Leptinotarsa decemlineata* Say) (× 6)

3 Shoots of cereal damaged by slugs, showing the characteristic "ribboning" of the leaves

4 Seed grain damaged by slugs



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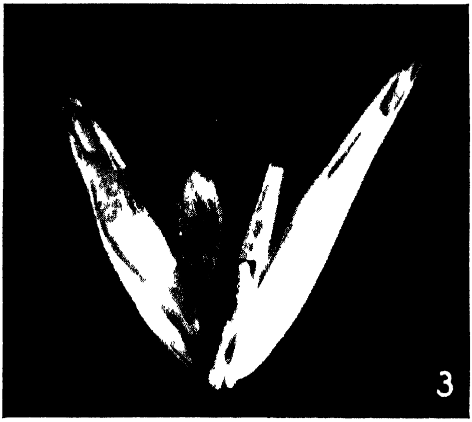

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PLATE XXX FRIT FLY ATTACK ON OATS

1 Left whole grains and kernels from oats attacked by frit flies Right normal grains and kernels Centre frit flies to show relative size

2 Oat plant attacked by maggots of frit fly showing stunted tillers

3 Pupae of frit fly in the grains of oat

proboscis. In bees, wasps, ants, ichneumon wasps and other parasitic Hymenoptera the body has a slender waist-like constriction near the junction of thorax and abdomen, but in the sawflies the abdomen is broadly joined to the thorax. Throughout the Order the females have well-developed organs for egg-laying called *ovipositors* (Plate XXIII). The saws of sawflies, the stings of bees and wasps and the piercing organ of parasitic species, which in some ichneumon wasps is about as long as the body, are all modified forms of ovipositor.

In the Hymenoptera there are two types of larvæ, the caterpillar-like larvæ of sawflies and the legless grubs of ants, bees, wasps and ichneumon wasps. Sawfly caterpillars can be distinguished from those of butterflies and moths by their large conspicuous eyes since caterpillars of Lepidoptera have clusters of tiny ocelli that cannot be seen without a lens, and by the absence of hooks or crotchets on the abdominal false feet or pseudopods. Like the caterpillars of Lepidoptera, sawfly caterpillars are green and inconspicuous, or brightly coloured, spotted or striped or clothed with large branched spines. The fleshy, white, legless grubs of ants, bees, wasps and ichneumon wasps spend protected, inactive lives surrounded by food.

Caterpillars and grubs of Hymenoptera usually pupate within silken or parchment-like cocoons. The pupæ are pale and soft and enclosed in a thin membrane which leaves wings and limbs free. The pupal period in summer generations of bees, wasps and ants may last about a week, or may extend over two winters in wheat stem sawfly and apple sawfly.

Reproduction by parthenogenesis, that is by unfertilised females, is common in Hymenoptera, and in some species (the honey bee and the pale spotted gooseberry sawfly (*Pteronidea leucotrocha* Hart.)) unmated females produce only males, while in others (the small green gooseberry sawfly (*Pristiphora pallipes* Lep.) and the greenhouse white fly parasite (*Encarsia formosa* Gahan)) females are produced and the species reproduces indefinitely without the intervention of males (Plate XXIV).

Social life reaches its highest development in bees, wasps and ants. In bumble bees (Bombidæ) and wasps (Vespidæ) the colonies start each year from fertilised females which shelter throughout the winter about buildings, hedges and evergreen trees. The colony depends on workers which are under-developed and barren females, and males are generally produced towards the end of the summer to ensure the fertilisation of overwintering females. Ant colonies persist year after year, but towards the end of the summer males and females are produced and, after fertilisation, the females lose their wings and settle in a small soil cell to lay eggs and start new colonies. The hive bee (*Apis mellifica* L.) has been carefully studied and its value as a pollinator in fruit plantations is widely recognised. A queen bee (fertilised female) may produce eggs for several seasons, and eggs, larvæ and pupæ are tended by workers. In an artificial colony or hive there may be over 30,000 workers engaged in cell-building, foraging and all operations necessary for the care and maintenance of the colony. New colonies are established by swarming, a swarm consisting of a large number of worker bees and a queen. Swarming in bees is related to the honey flow, and new colonies are formed only at times when food is sufficiently plentiful to allow them to become successfully established.

The Hymenoptera are divided into two main groups: the Symphyta or sawflies with a sessile abdomen, and the Apocrita which includes all the rest and is characterised by a waisted or petiolate abdomen.

SYMPHYTA are vegetable feeders and include many pests of fruit trees and bushes, forest trees, ornamental shrubs and flowers. The woodwasps or horn-tails (Siricidæ) are large insects with a stout ovipositor for piercing timber. The larvæ are wood-borers in dying or dead conifers. The stem-boring sawflies (Cephidæ) are slender insects with slightly clubbed antennæ whose larvæ live in the stems of grasses and cereals. The wheat stem sawfly (*Cephus pygmaeus* L.) attacks wheat in Europe and North America. The leaf-eating sawflies (Tenthredinidæ) often feed gregariously along the edges of leaves and may cause severe defoliation. Certain species are associated exclusively with particular host plants, and gooseberry, willow, larch, poplar, strawberry, hazel, spruce and pine have specific sawfly pests. Some sawflies are gall-formers, *Pontania* causing the red bean galls on the leaves of willows and *Euura* causing woody galls on the shoots. Fruit-eating sawflies feed in apples, pears and plums and are serious pests in fruit plantations.

APOCRITA, including ants, bees, wasps, ichneumon wasps, and other parasitic Hymenoptera, are mainly beneficial insects. Ichneumon wasps (Ichneumonidæ) are external (*ectoparasitic*) or internal (*endoparasitic*) parasites on other insects. *Rhyssa* is the largest British ichneumon and its long ovipositor is used to deposit eggs deep in timber in the feeding-tunnels of wood-wasp grubs. *Aphidius* feeds in the bodies of aphides. The fairy flies (Mymaridæ) are so minute that they reach their full development within the eggs of other insects, particularly those of leaf-hoppers and frog-hoppers. The gall wasps (Cynipidæ) cause galls on leaves and stems and the larvæ live in the galls. Many species are found on oak. The social wasps (Vespidæ) are well known for their attacks on ripening fruit, but it should not be overlooked that when they are rearing their brood they capture and destroy large numbers of injurious caterpillars. Solitary wasps (Eumenidæ) construct curious nests of mud. They lay eggs in the nest and fill it with caterpillars on which the wasp grub feeds. Bumble bees (Bombidæ) frequent flowers and are useful pollinators of farm and garden crops, but they often bite holes in the corolla tube of flowers of beans in order to reach the nectar easily. Ants (Formicidæ) have nests in the soil, in grass-grown humps above soil or in loose heaps upon the soil. Many species are predatory and feed on other insects which they dismember and carry to their nests. Ants are a nuisance in dwelling-houses and greenhouses, and ants' nests in dry meadows and pastures are associated with deterioration of the herbage.

Diptera (Flies). The true flies have one pair of membranous wings (Plates XX, XXI), the fore-wings, which are sometimes barred or mottled, and a pair of small knob-like structures, halteres or balancers, in place of hind-wings. The antennæ may be long and delicate as in gall midges and mosquitoes, short and slender as in crane flies and their allies, or short and thick and with a feathery bristle as in the blue-bottle fly, cabbage root fly and the hover flies. The eyes are large and conspicuous and in the males they occupy most of the top and sides of the head. The mouthparts show several types of adaptation for taking liquid food : mosquitoes have slender stylets for piercing and sucking, gadflies and clegs have stout lancets, and houseflies and root flies have a stout trunk with a lapping surface at the tip.

In Diptera metamorphosis is complete. The larvæ are legless maggots with fleshy retractile false feet and rows of spines to help them to move about. Maggots of St. Mark's flies, false leatherjackets (*Bibio* spp.) which live gregariously at the roots of grass and cereals, and the slender maggots of fungus gnats which live in mushrooms and in decaying plants, have distinct black heads with biting jaws. Leatherjackets, the maggots of crane flies (Tipulidæ), have biting jaws, but the head is small and incomplete and withdrawn into the body (Fig. 78, *g*). Maggots of root-feeding flies and blow flies are practically headless (Fig. 78, *e*) ; the jaws are reduced to a pair of strong, downward-curving hooks (Fig. 79) which lie side by side and tear at food material as they are pushed forward and retracted again in an almost continuous rhythmic motion. Most of these degenerate maggots have delicate skins and live surrounded by moisture among decomposing plant and animal tissue. Some are injurious to crops and stock but many are scavengers and play a useful part in the disintegration of plant and animal remains.

There are two distinct types of pupæ among the Diptera. In crane flies, mosquitoes, gnats and midges the fully grown maggot casts the larval skin and reveals a pupa which shows the outlines of wings and limbs (Plate XX). In houseflies, rootflies, frit flies and warble flies the last larval skin hardens to form a barrel-shaped chrysalis called a *puparium.* The pupa is sheltered and protected within the puparium, which bursts open at one end when the fly is ready to emerge.

Flies usually reproduce by laying eggs. Some flesh flies (Sarcophagidæ) and parasitic flies (Tachinidæ) retain the eggs within the body of the female until hatching takes place, and in consequence they are said to be *larviparous*, that is, they deposit living larvæ. Another group of flies is known as Pupipara from their habit of nourishing the larvæ within the bodies of the females. The pupiparous flies are external parasites on the bodies of animals and birds, the forest fly (*Hippobosca equina* L.) feeding on horses and cattle, and the sheep ked (*Melophagus ovinus* L.) (Fig. 92) feeding on sheep. They deposit their fully grown maggots on the ground, or in places frequented by their hosts, and pupation takes place at once. In some of the gall midges (Cecidomyidæ) reproduction by egg-laying adults is supplemented at certain times of the year by larval reproduction or *pædogenesis*, that is, the maggots give rise to other maggots.

Pædogenesis may continue as long as temperature and food supply are favourable but, after a few pædogenetic generations of larvæ, development becomes normal again, pupæ are produced, and egg-laying flies reappear in the cycle.

The Diptera contains many families of flies important to man and his crops and stock. Crane flies or daddy-long-legs (Tipulidæ) (Plate XX) form an extensive family of long-legged flies, some of which are small and fragile like mosquitoes, while others are nearly 2 in. long with hard black and yellow bodies and mottled wings. Their maggots are called leatherjackets and are often injurious to crops in poorly drained fields and weedy gardens. Mosquitoes (Culicidæ) are notorious the world over as carriers of malaria, yellow fever and ague. They lay eggs in water, either singly or in small floating masses. The larvæ are aquatic and live on minute aquatic creatures. They obtain air through pores (spiracles) at the tip of a tubular projection arising near the tail. Pupation takes place in the water ; the pupæ retain the power of movement and obtain air through tubes in the thorax.

Gall midges (Cecidomyidæ) cause various deformities to stems, leaves, flowers and fruit. The maggots are red, pink, orange, yellow or almost colourless, and usually have a small horny, slightly forked, breast bone (anchor process) on the underside. Injurious gall midges include the hessian fly (*Mayetiola destructor* Say.), an important pest of wheat in the United States ; blossom midges (*Contarinia*, *Sitodiplosis*) which feed on developing wheat grains ; swede midge (*Contarinia nasturtii* Kieff) which feeds in the terminal bud of swedes and other Brassicas ; pea midge (*Contarinia pisi* Winn.) which feeds in the pods of peas, and the pear midge (*Contarinia pyrivora* Riley) which feeds in the young fruits of pear. The fungus gnats (Mycetophilidæ) feed in fungi and decaying plants, and their maggots have been found in large numbers in rotting swedes, mangels, potatoes, bulbs and mushrooms.

Many of the short-horned flies (Brachycera) are beneficial insects. Both larval and adult stages of down-looker flies (Leptidæ), robber flies (Asilidæ) and stiletto flies (Therevidæ) are carnivorous. Larvæ of bee-flies (Bombyliidæ) are parasitic. The horse flies, gadflies and clegs (Tabanidæ) (Plate XXI) are large stout-bodied flies whose females are vicious biters of both man and stock. They are strong active fliers and settle on their hosts with such lightness and precision that the sharp prick of the piercing proboscis is often the first indication of their presence. The males are harmless and feed on nectar, and the larvæ live in damp meadows and ditches along the edges of woodland and feed on small earthworms, woodlice and insects.

The hover flies (Syrphidæ) are rather large handsome flies, often with black-and-yellow-barred bodies that give them a wasp-like appearance. They abound almost everywhere in woods, fields and gardens, and the high-pitched hum they produce as they hover over flowers is characteristic. The flies feed on nectar. They lay eggs near aphis colonies and the rugged green, pinkish or yellowish maggots feed entirely on aphides. The chrysalids are pear-shaped and are found attached to leaves, stones, twigs and bark of trees.

Maggots of bee-like hover flies called drone flies (*Eristalis*) live in liquid manure tanks and in water in holes in trees, and their long breathing tubes have earned them the name of " rat-tailed maggots ". The narcissus flies (*Merodon equestris* F., and *Eumerus* spp.) are among the few injurious hover flies ; their larvæ feed in the bulbs of narcissus and onion and in the crowns of rhubarb.

In a large group of flies, the Schizophora, the adult at emergence forces open the puparium by inflating the intersegmental membrane (*ptilinum*) of the face. After emergence the ptilinum is gradually deflated and withdrawn into a crescent-shaped scar (*frontal suture* or *lunule*) lying above the antennæ. Many important fly pests are members of this group. Frit flies and gout flies (Oscinidæ) attack the shoots and flower heads of cereals all over the world. The carrot flies (Psilidæ) are small shining blue-black flies whose maggots feed on the tap roots of carrots, parsnips and celery and may render them unfit for market ; closely related species infest the root stocks of chrysanthemums and the tap roots of lettuce. Leaf-mining flies (Trypetidæ) with characteristic mottled wings (Plate XXI) feed in the leaves of celery, parsnip, parsley and chrysanthemums in irregular blotch mines, while other leaf-miners (Agromyzidæ) make long winding tunnels in chrysanthemums, clover and cereals. Dung flies (Scatomyzidæ) are the common yellowish and brownish flies often seen in great numbers about fresh cow dung. The flies are predacious upon small insects and the maggots live in excrement.

The bot flies and warble flies (Œstridæ) are large bee-like flies whose larvæ are parasites of horses, cattle and sheep. The horse bot flies (*Gasterophilus*) are found in the stomach of the horse ; warble flies (*Hypoderma*) live in the backs of cattle, and maggots of the sheep nostril fly (*Oestrus ovis* L.) inhabit the nasal cavities of sheep. Tachina flies (Tachinidæ) are stout, medium-sized bristly flies, usually grey and black, which lay eggs or larvæ upon caterpillars, grubs and other insects. Tachinid maggots are internal parasites ; they completely devour their hosts and often form chrysalids within the host's body. The blow flies, green bottles and blue bottles (Muscidæ) frequent dead animals, decaying organic matter and excrement, and their maggots live in similar situations. Many are scavengers and consequently are beneficial, though they are carriers of bacteria to food and milk in houses, shops and dairies. Green bottle flies and some blue bottles at times lay their eggs about the tails of sheep and lambs and the maggots may penetrate the flesh and cause the death of infested animals. There are several generations of blow flies and their relatives during the year and they pass the winter in the soil as larvæ or pupæ ; adults hibernate in the shelter of buildings, shrubs and evergreen trees. The root flies (Anthomyidæ) frequent decaying vegetation and freshly turned soil. The cabbage root fly, wheat bulb fly, mangel fly and bean seed fly are major pests of farm and garden crops, but many related species are scavengers upon decaying tissue or are predators that seek a living among the soil fauna.

PRINCIPLES OF INSECT CONTROL

The control of insect pests can be attempted in a number of ways. Before describing these reference must be made to the natural factors which adversely affect insect increase, namely, the action of unfavourable weather, parasites, predators and, in the final result, exhaustion of food supply. The interaction of these factors produces fluctuations in insect populations from season to season so that a particular pest is now relatively scarce, now in epidemic proportions. The study of these events with a view to ultimate prediction is a main concern of the entomologist. By these influences insect numbers are kept within bounds over a period, but it is small comfort to a grower whose crops are at the moment being destroyed to know that next year, or the year after, his plants will escape attack. Therefore he must have at hand weapons he can use the moment his crops appear to be seriously threatened.

These " artificial " control methods may be conveniently classified into the indirect and the direct. *Indirect* control measures consist mainly of the modification of ordinary farm practices, giving them a twist, as it were, so that they act against the pest or pests. Consequently they are inexpensive and examples are the arrangement of ploughing and sowing dates to the best advantage (frit fly, leatherjacket, wheat bulb fly, slugs) ; correct rotations (eelworm) ; and the growing of resistant varieties. *Direct* control refers mainly to the use of specially prepared chemicals (insecticides), and since these are not inexpensive, economics become important. Therefore, for the most part, chemical methods tend to be used in the horticultural and fruit industries with their higher turnover, though the development of the more potent insecticides and the low-volume sprayer have in fact considerably extended the possibilities of use in general agriculture.

Chemical Control. The spate of new chemicals available for trial as insecticides since the war is a new phenomenon and shows little sign of abating. Not only are new and better substances available but diverse formulations (light and heavy dusts, wettable powders, emulsions, aerosols, smokes, etc.) designed for different purposes still further increase their effectiveness. Machinery is now available for applying the insecticides and there has emerged the spraying contractor. The position in general agriculture, therefore, is a very different one from that prevailing not so very long ago when the poison bait was about the only chemical control that could be prescribed and when, indeed, if a spray was suggested there was no means to apply it.

In the fruit world, however, there may be said to have been a tendency to the reverse. Between the wars a complicated annual routine (not to say ritual), the " winter washing programme ", had developed, using tar oils, DNC, petroleum oils and other compounds in their variety. But more recently the view has gained ground that the logical process is to spray according to the needs of the orchard rather than according to the calendar. The new insecticides have facilitated this, and it is now possible to get reasonable control of orchard pests by omitting winter washing altogether.

The New Insecticides. It used to be convenient to classify the old insecticides according to their mode of action. Thus certain pests like aphids were best controlled by sprays aimed directly at them and acting by *contact* via the cuticle or the spiracles : examples are nicotine, pyrethrum and derris. Other pests, those with biting mouthparts, could best be poisoned by spraying the foliage of the attacked plant with a *stomach poison*, the best example being arsenate of lead. Finally, there were other pests, notably the carrot fly and the cabbage root fly, against which neither type of insecticide was effective ; here the attempt was made to repel the insect, or perhaps to disguise the food-plant, by using strong-smelling substances or *repellents* like naphthalene and creosote. So, the first essential, the detailed working out of life history of the pest, having been observed, the most suitable of these methods would be applied.

The new insecticides have improved the position very considerably. Their main characteristics are their extreme potency, their ability to act both as stomach and contact insecticide so that the old distinction between these becomes somewhat blurred ; and most important of all, their persistence. This means that instead of repeated spraying being necessary, a single spraying will remain effective for days or, in some cases, weeks. This is a great advantage to the grower. Some examples of new types of formulations have already been referred to, but special mention must be made of the seed dressings now available for use against wireworms, flea beetles and the carrot fly. These developments, if their success can be sustained, are of the first importance.

One other advance must be mentioned, and that is the emergence of the *systemic* insecticide, a chemical that is actually taken up by the plant by absorption through leaf or root like a nutrient solution and which is moved in the sap stream through the whole system of the plant. An insect sucking up such sap, even after a lapse of several days, or in some cases weeks, is poisoned.

Before referring in more detail to the main types of the new insecticides, two drawbacks resulting from the property of persistence should be pointed out. First, spray residue problems assume a new importance, a matter that closely interests the consumer ; secondly, and this applies mainly to the soil insecticides, the possibility of continual dressings leading to " build-up " in the soil must be watched.

The Chlorinated Hydrocarbons. These form the first and one of the most important series to be developed. The two best known are DDT and BHC (benzene hexachloride), both now well established. Their uses are in some ways similar, but BHC finds particular application against soil pests and in the production of the seed dressings already mentioned. This development has been made possible by the separation of the gamma isomer, as described on page 400. More recently two important newcomers have arrived. These are aldrin and dieldrin, named in honour of their discoverers, Alder and Diels. They have similar applications to BHC, but aldrin can in addition be used to protect the potato from wireworm attack which BHC could not do because of taint.

The Organo-Phosphorous Compounds. Discovered first by Schrader in a Germany cut off from supplies of nicotine, this series of compounds is an extremely powerful one. The first to be introduced was hexaethyl tetraphosphate (HETP), the effective constituent of which was later found to be tetraethyl pyrophosphate (TEPP). This is the most powerful mammalian poison of them all, but since it breaks down into harmless residues soon after application is in that respect the safest to use. The well-known parathion is absorbed into the surface cells of foliage on which it is sprayed and so is especially useful against aphids in curled-up leaves. The next type of compound discovered by Schrader was the true systemic insecticide. It was named schradan in his honour and was developed for use in this country on commercial crops, in particular against the mealy cabbage aphid, hop aphid and hop red spider and some other pests. Other related systemics followed, notably demeton methyl and dimethoate which because of their lower mammalian toxicity could be sprayed without protective clothing. This in effect made the ordinary farmer independent of the contractor—he could deal with his aphid problems himself—and constituted a great advance. Many other organophosphorous systemics have since been introduced and to these must be added a systemic based on quite another compound, fluoracetamide. This, however, needs protective clothing. Because of their poisonous nature the application of the new insecticides is controlled by legislation and the consumer is protected by recommendations. Finally two non-systemic organophosphorous compounds introduced after parathion and with similar insecticidal properties must be mentioned. These are malathion which is one of the safest existing insecticides and is used by both commercial growers and amateurs, and diazinon which has a higher mammalion toxicity.

The New Acaricides. Mention must be made of certain materials which appear to have solved the red spider mite problem of fruit trees, at least temporarily. For the most part they are chlorinated and sulphonated benzene ring compounds, the most important being chlorobenzilate, chlorparacide, *p*-chlorphenyl-*p*-chlorbenzene sulphonate (CPCBS) and *p*-chlorphenyl benzene sulphonate (PCPBS), and related compounds. The organophosphorous systemics are also very efficient.

Biological Control. Biological control seeks to make use of natural enemies for the control of pests. It has been successfully developed in America where the fluted scale (*Icerya purchasi* Mask.), a pest of citrus trees, had been introduced without its natural enemy, a ladybird beetle, *Novius cardinalis* Muls. The introduction and establishment of the ladybird in citrus-growing states effectively checked the ravages of the scale insects. Under the stable agricultural conditions prevailing in Britain natural control is an important but not a spectacular method of pest control. Almost every species of insect has its parasites and predators and the examination of an aphis colony will give some indication of the extent of their activities. It is usual to find the grubs of ladybird beetles, the maggots of hover flies, numbers of small black ichneumon wasps and the grubs of lacewings all congregated about the colony and feeding upon the aphids. In this country effective use has been made in the past of the parasite introduced from the Far East—*Encarsia formosa* Gahan—

to control the greenhouse white fly. In the orchard, *Aphelinus mali* Hald. was introduced many years ago from U.S.A. to control woolly aphid. Though it took some time to become established it can in some years be remarkably effective but may not overwinter successfully.

Legislative Control. Legislative measures are occasionally adopted to prevent the introduction and establishment of new pests and to check the increase of those already established. The Colorado beetle (*Leptinotarsa decemlineata* Say.) is a notifiable pest and, when its presence is reported to the Ministry of Agriculture, steps are taken to secure the complete destruction of the pest by supervised spraying and soil-treatment. Other pests that have been the subject of legislation include the fluted scale (*Icerya purchasi* Mask.), chrysanthemum gall midge (*Diarthronomyia chrysanthemi* Ahl.), mediterranean fruit fly (*Ceratitis capitata* Wied.), potato moth (*Phthorimaea operculella* Zell), vine phylloxera (*Phylloxera vastatrix* Planch.), and amongst stock pests, the ox warble fly and the sheep scab mites.

A successful experiment in legislative control has been the enforcement of an adequate rotation in fields in the east of England where beet eelworm (*Heterodera schachtii* Schmidt) is known to occur. This measure has maintained yields of beet and prevented waste of land and labour in efforts to produce sugar beet on land where the eelworm population is so high that it constitutes a serious risk to the crop.

Indirect Pest Control. Most agricultural crops are mass cultures of plants with a comparatively low individual value, and farmers generally adopt indirect methods of pest control because they involve little or no outlay and can be carried out as part of the routine of crop production.

Cultivations. These often take the form of advancing or delaying the time of routine cultural operations in order to create unfavourable conditions for particular pests. It is an advantage to plough ley or pasture before corn harvest in order to prevent frit fly oviposition on rye grass in the ley. When leys are ploughed late, frit fly maggots feeding in the shoots of rye grass are able to survive ploughing operations and they finish their development in the seedlings of the new corn crop. In east and central England where wheat bulb fly (*Hylemyia coarctata* Fall.) is prevalent, the aim should be to cover the ground in late summer with a forage crop like rape or common turnips or a green manure like mustard so that there is no bare soil to attract the egg-laying flies. Cultivation to keep down weeds is also an important factor in pest control. Weed grasses like couch and bent harbour pests of cereals, and charlock and knot-grass harbour pests of Brassicas and beet. Weeds encourage egg-laying by owlet moths and afford food and shelter for the young cutworms.

Time of Sowing. Time of sowing affects the incidence of such pests as frit fly, flea beetles and carrot fly. Over most of Britain spring oats are sown in April and attack by frit fly is general. Crops sown during February and March are usually well established before frit flies are on the wing in great numbers and infestation is negligible, but crops sown in late April and May often suffer severely from frit fly attack. In districts where flea beetles cause heavy loss farmers try to avoid attack by advancing or retarding the date of sowing Brassica crops so that the emergence of the seedlings does not coincide with hot dry weather and maximum beetle activity. Late sowing is commonly practised to avoid loss to carrots by carrot fly. The new seed dressings have, however, made these practices less necessary.

Time of Harvesting. Damage to potato tubers by wireworms and slugs can be limited by early harvesting. The autumn feeding period of wireworms usually begins in September, and wireworm injury to potato tubers increases steadily during autumn if they are left in the ground after the middle of September.

Crop Rotation. Pest control by crop rotation is of the greatest value against specific pests like root eelworms which have an exceedingly low capacity for migration. Losses from attack by potato root eelworm (*Heterodera rostochiensis* Woll.), beet eelworm (*H. schachtii* Schmidt), oat root eelworm (*H.avenae* Woll.) and pea root eelworm (*H. göttingiana* Lieb.) can be reduced by increasing the interval between host crops. It is hardly an exaggeration to say that these eelworm pests, especially the root eelworms, are a greater threat to agriculture even than insects. Since rotation is the only effective means of preventing eelworm attacks, and the only means of dealing with them should they occur, the importance of rotation in modern agriculture can scarcely be stressed enough. It should be remembered that once a cyst population has been built up to danger level, the soil is likely to remain always infected.

On the other hand, neglect of crop rotation and the cultivation of a limited range of crops within an area are followed by severe infestation by specific pests capable of migrating from field to field. Intensive carrot growing in certain districts has built up such high local populations of carrot fly that the production of clean carrots is almost impossible. Similarly, many market-growing areas have high populations of cabbage stem weevil and turnip gall weevil (*Ceuthorrhynchus* spp.), flea beetles and cabbage root flies. Overcropping with cereals in parts of the south of England during the inter-war years built up high populations of gout fly (*Chlorops taeniopus* Meig.) and wheat stem sawfly (*Cephus pygmæus* L.) which were locally destructive during the war years when cereal growing was compulsory.

Manuring. The use of manures and fertilisers has little direct influence on the prevalence of insect pests. The value of manures lies in their effects on the plants. They serve to promote plant growth and vigour, and produce healthy robust plants generally able to withstand insect attack. The early establishment of cereals in fertile soil is of prime importance in preventing loss of crop through wireworm attack, and sugar beet, mangel and barley seedlings are especially susceptible to soil acidity. Combine drilling fertiliser with the oats may circumvent frit fly attack.

Farm Hygiene. Proper attention to the disposal of crop remains makes an appreciable contribution to pest control. Mustard beetles, wheat stem sawfly, pea and bean weevils and cutworms shelter in the stubbles of various crops. Burning hedgesides, and the stubble of cocksfoot seed crops in autumn and early winter does much to check cocksfoot moth. The chrysalids of this pest hibernate in the old flowering stems. Early and deep ploughing of stubbles buries hibernating insects and may prevent their survival and emergence in the following spring. Bulky crop residues should be buried deeply, preferably after an application of calcium cyanamide or sulphate of ammonia to promote rotting.

The storage of crops should be done carefully to avoid loss from rotting and from the attacks of secondary pests like woodlice and millipedes. When the clamped crops of potatoes, carrots and other roots are finally removed it may be advisable to treat the site with soil insecticides to destroy slugs, wireworms, eelworms, carrot flies and other pests that have left the crop and entered the soil below the clamp to complete their development. Mangel clamp hygiene is a matter of urgency to avoid the spread of virus yellows. Corn bins, granaries and forage stores should be thoroughly cleaned and disinfected before new crops are stored : this has assumed special importance since the introduction of the combine harvester and the consequent storage problems. Walls should be faced with cement to prevent insects sheltering in the crevices and a light dusting of a suitable insecticide such as DDT, BHC or malathion on walls and floor, or more conveniently the same substances in the form of " smokes ", will destroy many wandering insects without affecting the palatability of stores in sacks and bins.

Soil and crop debris in sacks and other containers should be burnt. This is especially important in the case of sacks used for seed potato tubers since they may sometimes contain cysts of potato root eelworm.

Clean Seed and Healthy Plants. The purchase of clean seed of good quality is always worth while. Important pests like stem and bulb eelworm (*Ditylenchus dipsaci* Kühn) are carried on the seeds of onion, oats and clover and ear cockle eelworms (*Anguina tritici* Steinb.) are carried in wheat seed. It is also advisable to know something of the history of fields from which Brassica seedlings, strawberry runners and onion sets are purchased for the cysts of root eelworms and the infective stage of stem eelworm are often carried to new sites in soil at the roots of purchased plants.

Birds and Animals as Agents in Pest Control. Plovers (peewits or lapwings) feed almost exclusively on insects ; they destroy wireworms, leatherjackets, chafers, slugs and snails in grassland, and these and other insects in arable land. Rooks, jackdaws, magpies and starlings also feed on grassland insects. It has been estimated that about a ton of insects is distributed over each 5 acres of grassland and each 20 acres of arable land, and the insectivorous birds help to prevent an excessive increase in the insect population. Blackbirds, thrushes, warblers and chats are active in destroying insects about crops and fruit plantations, especially during the breeding season. Mice, voles, shrews and hedgehogs, together with reptiles, lizards, frogs and toads also play a part in keeping down the numbers of insects.

MAJOR PESTS OF FARM CROPS AND STOCK

In the following account of some of the more important insect and allied pests of farm crops and stock attention is focused on life history and habit, and for details of structure the student should refer to the appropriate paragraph in the section on the classification of insects on pages 410–421.

PESTS OF CEREALS

Wireworms (Plate XIX, Fig. 78, *a*). Wireworms are the grubs of click beetles (Elateridæ). Their natural home is grassland, and because cereals are usually the first crop after ley or grass, wireworm injury is generally associated with cereal crops though it can be equally severe on sugar beet, potatoes, Brassicas, market garden crops and strawberries. Wireworm feeding is greatest in autumn during September and October, and in spring from March to May. Autumn-sown cereals are subject to attack at both periods and spring-sown cereals are attacked before they are established. Attack by wireworms consists of hollowing out the grains, severing young plants from the seeds and primary roots, and tunnelling in the crown of the established plants so that shoots and tillers are destroyed. When wireworm attack occurs simultaneously with low fertility and adverse weather conditions the crop may die over large patches and re-drilling may be necessary.

Wireworms are smooth, slender, yellow grubs, $\frac{3}{4}$–1 in. long when fully grown. The head has strong biting jaws and the body consists of twelve segments, the first three of which bear the true or thoracic legs and the last segment bears a single false foot and has two small brown oval pits on its upper surface. Wireworms hatch from eggs laid in the soil in early summer. They feed intermittently and grow so slowly that they require at least four years to reach maturity. During the fourth summer they make earthen cells in which they become soft white chrysalids, and about a month later the beetles emerge. Newly formed beetles may shelter in the pupal cell throughout the autumn and winter, or they may leave the cells and shelter in the soil, under clods or in thick herbage.

The common click beetle of grassland (*Agriotes obscurus* L.) is about one-third of an inch long, elongate-oval in shape and brownish in colour. The antennæ are slender and about one-third of the length of the body ; legs and antennæ may be held so close to the body that the beetle is not easily seen in the soil. Click beetles feed on the leaves of grass, cereals and clover but do little harm. In spring they are often found in pieces of turf on recently broken grassland.

Insects with a long larval feeding period occur under stable conditions, and wireworms are found most abundantly in permanent grassland where the surface has been undisturbed for a long time and fluctuations of temperature and humidity are at a minimum. Wireworm populations vary greatly with the geographical position, altitude, soil, drainage and agricultural history of the land, and numbers may rise as high as three millions per acre. As long as fields are under grass the wireworm population is of negligible importance, but when grassland is ploughed for arable cultivation wireworms are a menace for two or three years. Ploughing creates unfavourable conditions for egg-laying and the survival of young wireworms, and in consequence the wireworm population gradually diminishes when grassland is cultivated. Approximately a quarter of the wireworms reach maturity each year and, since the numbers are not appreciably replenished, the low wireworm populations characteristic of arable land are usually reached by the fourth year of cultivation.

Wireworms are not generally a serious pest of agricultural crops on established arable land, but when wireworm injury coincides with lack of fertility, water-logging, adverse weather or other conditions unfavourable to plant growth, it has an exaggerated influence on the backward crop.

Control Measures. Loss from wireworm attack on new arable land may be limited by growing resistant crops, by increasing the seeding rate of cereals even up to 50 per cent or by cross drilling, and by ensuring for the crop a firm seed bed in fertile soil. Good ploughing and consolidation and, where necessary, the correction of lime and phosphatic shortages likely to be present on old grassland are essential. In recent years, however, the wireworm problem has been completely changed by practical methods of direct chemical control. The first successful step in this was the introduction of a crude low-content benzene hexachloride dust which was applied direct to the seed bed. Crude BHC consists of a mixture of four or five isomers of which only one, the gamma isomer, is effective as an insecticide. The separation of this isomer on the commercial scale was the next step, making possible the production of a low-content dust in which taint hazards were considerably lessened. Perhaps the most important result, however, was the development of concentrated high-content gamma BHC seed dressings which, combined with the already established mercurial fungicidal dressings, provided a dual protection for cereals and beet in all but the heaviest infestations—at any rate with spring crops. Aldrin is equally successful against wireworm and can be used on the potato crop without causing taint. This means that potatoes can now be successfully taken after old grassland infested with wireworm, a course hitherto not possible. However a word of warning must be given here. Aldrin and dieldrin are very slowly broken down in the soil and repeated dressings may build up soil residues.

Leatherjackets (Plate XX, Fig. 78, *g*) are the tough-skinned, grey-brown, legless grubs of the daddy-long-legs or crane fly (*Tipula* spp.). They constitute one of several pests—notably the slug, frit fly, wheat shoot beetle, rustic moth—any or all of which are liable to attack cereals after ley when ploughing and sowing closely follow one another. In recent years much attention has been paid to leatherjacket numbers : by a fairly simple technique, populations can be estimated and the general level of attack can be forecast with some accuracy. A very high peak was forecast in 1952, since when numbers have been declining. It is possible that the next peak will occur around 1962.

Crane flies lay their shining black eggs in the herbage of damp fields in late summer and early autumn. The eggs hatch in about a fortnight, and the grubs feed during the winter. In some years serious damage may be done by the turn of the year. In spring they vary in length from one-half to one inch, and can speedily cause damage to germinating and seedling cereals, root and other crops. Whole fields may be destroyed. Pupation takes place in the soil in summer, and the crane fly emerges, leaving the empty pupal case protruding from the soil. There is one generation per year.

Control Measures. Fortunately, control is fairly cheap and satisfactory by use of the well-known poison bait, 1 lb. Paris green to 30 lb. bran broadcast per acre. Recently it has been found that a somewhat cheaper, convenient, effective and less poisonous substitute for the Paris green is 1 lb. of 50 per cent wettable DDT or BHC spray powder. The bait should be only slightly dampened so that the flakes do not adhere, and the broadcasting should take place towards evening, for the leatherjackets come to the surface at night to feed. More recently still, sprays of DDT or aldrin have been used, and this method is worth a trial even at low volume.

Frit Fly (*Oscinella frit* L.) (Fig. 77). Frit flies are small shiny black flies about $\frac{1}{12}$ in. long which can be found from spring to early autumn. There are three main phases to their attack. First, in May eggs are laid on the seedling oats and the maggots attack and kill the centre shoot, which typically turns yellow. Flies resulting from this attack lay their eggs in the glumes of the developing panicles and the maggots eat out the young grain. As much as 50 per cent grain attack has been recorded. Flies from this generation frequently cover the outsides of stooks and stacks and the insides of barns. Eggs are then laid in the grasses in leys, rye-grasses especially, on volunteer corn or early sown cereals, producing the autumn shoot attack. Often when a ley is turned in and corn sown immediately, the larvæ leave the buried rye-grass and attack the young cereal seedlings. These autumn larvæ live through the winter and give rise to the flies of the May attack already mentioned. The generations may overlap somewhat, and a late shoot attack in June may result in damage to the developing ears, producing a sort of blindness which is, however, quite distinct from the more common " blast ". Frit fly attack is mainly associated with oats, but wheat is also affected.

Control Measures. Frit fly attack causes annual loss at one level or another both in the shoot and in the grain. The latter is more easily estimated and records show that a 10 per cent grain attack is a fair average figure : but as has already been mentioned, in some fields a figure of 50 per cent has been recorded. Work is at present in progress to see to what extent the low-volume sprayer using a substance like dieldrin or DDT is an economic proposition in reducing the loss.

The only other practical measure of control is early sowing against the early summer shoot attack. Dates vary somewhat, but February and March sown crops are usually safe, while May and later sown crops can be almost complete failures. An exaggerated example of the latter is where oats are attempted as a catch silage crop after early potatoes. They may never get beyond the "grass" stage.

Wheat Bulb Fly (*Hylemyia coarctata* Fall.). This insect used to be known as a more or less localised pest of wheat following land that had been fallowed in August. Recently, it appears to be equally dangerous after potatoes, both early and late, and root crops. The epidemic of 1953 on the east side of England when thousands of acres of wheat were destroyed will be long remembered. Fortunately since then the damage has been on the decline.

Eggs are laid from late July to the end of August in dry, dusty, bare soil. Hatching takes place the following February onward and the grubs mine into and kill the central shoot in much the same way as with the frit fly. If the wheat is well tillered heavy attacks can be withstood, but untillered wheat rapidly succumbs.

The most successful control measure is early October sowing in wheat bulb fly areas. The 1953 epidemic stimulated much research resulting in the development of suitable seed dressings of BHC, aldrin, dieldrin and heptachlor. In view of the danger of the last three named to wild life, it is officially recommended that they be used only in certain of the worst affected areas and should not be used after the end of December, i.e. on autumn-sown corn only. A specially prepared wheat bulb fly aldrin-containing fertiliser is also available for use in the combine drill.

Corn and Grass Aphids. Three species of aphids may in epidemic years do appreciable damage to corn and grass and are also capable of spreading a virus disease, Barley (Cereal) Yellow Dwarf. The three species are *Rhopalosiphum padi* L. *Metopolophium festucae* Theob. and the grain aphid *Sitobion* (*Macrosiphum*) *avenae* F.

Slugs are persistent pests of young cereals. During autumn and winter, seed grains may be hollowed out and young seedlings damaged so that the leaves are frayed in a very characteristic manner. Slugs are more numerous in the heavier, damper soils. They live in the soil and vary slightly in their feeding habits according to species. The grey field slug (*Agriolimax reticulatus* Müll.), for example, feeds mainly at the soil surface in damp mild weather, hiding in the ground during daylight or cold weather. The underground or keeled slugs, which infest gardens and horticultural land, feed especially on the underground parts of crop plants, and because they spend most of their time beneath the surface are correspondingly more difficult to control with surface baits. Eggs are laid in clusters in the soil and rotting vegetation. They are spherical and translucent, about $\frac{1}{12}$ in. in diameter. The young slugs hatch in about a month.

Control Measures. Slugs flourish in damp soils rich in organic matter and the opposite conditions tend to discourage them—the use of fertilisers instead of farmyard manure, for example. On a small scale, clearing of plant debris is helpful. Direct chemical control consists mostly of the use of metaldehyde, and this remarkable substance has considerably eased the position. Bait, made of 1 lb. metaldehyde to

30 lb. bran, is the cheapest form : but in the darker months when the sun has less power, a mixture of 1 lb. Paris green, ½ lb. metaldehyde, 30 lb. bran is more effective (it is also useful against leather-jackets). Recently the contact action of metaldehyde has been exploited and wettable powders for spraying have been marketed, but the cost of these limits them to special work. Copper sulphate is an old but effective slug-killer where it can be employed.

Slugs have many natural enemies of which the duck is probably the best known. Pheasants, partridges, wood-pigeons and other birds devour them, and ground beetles feed on young slugs.

Eelworms. Two main types are concerned, the Stem eelworm (*Ditylenchus dipsaci*) which distorts the shoot and causes " tulip root " in oats (Plate XXVI), and the possibly more serious Root eelworm (*Heterodera avenae* Woll.) which, like its better known relation the Potato Root eelworm, disorganises the root system in which it forms cysts. These cysts are persistent and may keep the soil infected for many years. In both cases the trouble is brought about by unwise rotations, i.e. the too frequent cropping of oats. But whereas in the case of the stem eelworm loss may be minimised by growing other cereals or by growing varieties of oats which are to some extent resistant (S. 172, Picton, Pennant, Manod and Milford), in the case of the root eelworm there is no effectively resistant oat and all the other cereals and the grasses act as hosts to the pest and keep infection going. Therefore rotation in the pest control sense is quite a different matter, and therein lies the especial threat of the cereal root eelworm. As a result, the different aspects of this pest are being actively studied, while the control of the stem eelworm remains the concern of the plant breeder, i.e. resistant varieties.

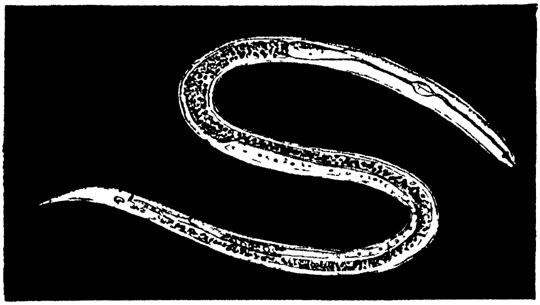

FIG. 85.—STEM ELLWORM (*Ditylenchus dipsaci*), ADULT ♀ : × 160, showing position of mouth spine.

PESTS OF SUGAR BEET AND MANGELS

Mangel Fly (*Pegomyia betæ* Curtis). The mangel fly, like the root flies, is brownish-grey and about the same size as, but more slender than, the housefly. The eggs are white, elongated and sculptured, and are laid usually in clusters on the undersides of the leaves of mangels and beet. They are easily visible with the unaided eye and should be recognised by the farmer since control measures depend on this. In a few days the young larvæ hatch and enter the leaves, forming bladder-like tunnels which, if the attack takes place early, can destroy all the assimilating tissue. When full fed the maggots desert the leaves and pupate in the soil. Later a second generation occurs which can cause extensive defoliation of the full-grown plants.

Control Measures. Mangel fly attack always looks much worse than it really is, for even when defoliation has been so severe that a burnt-up appearance is produced, recovery is usually complete and loss in ultimate yield is small. However, in very severe cases there is undoubtedly some delay and slight loss : now that a fairly cheap control is within the reach of the farmer who possesses a low-volume sprayer the economics of the situation are rather different. A convenient material to use is DDT emulsion ; unnecessary spraying with DDT causes harm to predators. If spraying has not been done a top dressing of a nitrogenous fertiliser is advantageous.

Black or Bean Aphid (*Aphis fabæ* Scop.). This is perhaps the best known of the aphids because of its partiality for the broad bean. Its life history is one of classic interest. During the summer months it feeds mainly on the undersides of the leaves, causing them to curl and in bad cases to wither. Towards autumn a migration takes place to the spindle tree where mating is accomplished and eggs are laid. It is possible from a numerical estimate of these eggs to form a fair forecast of the potential outbreak the following season, although the weather of spring and early summer has the final say. The eggs hatch in early spring and large colonies of aphids are produced which begin to migrate from April onwards. Many go to beans, but early beet may also be infested and in such cases serious damage is possible in June and July from this primary infestation. Often, however, and this is especially true of the western areas, the main migration is a secondary one, largely from the bean crop, in July. The capacity for damage is then much smaller, because by August the colonies usually begin to die away, largely from fungus attack. It is the survivors that return to the spindle tree.

Control can be readily achieved with one of the systemics ; in the case of sugar beet an effective system of spray warnings has been developed and is carried out in conjunction with the factories.

Peach-Potato Aphid (*Myzus persicæ* Sulz.) (Fig. 82). This small, greenish aphid is really a greater threat to the beet crop than is the bean aphid, for though it is much less spectacular and will probably not be noticed by the average farmer, it introduces and spreads the well-known yield-and-sugar-reducing virus, Sugar Beet Yellows (see p. 391). The bean aphid does take some small part in this spread but it cannot introduce the virus. The damage done depends on the time of infection. If it goes ahead early in the season, say in June or early July, the loss may be serious. If it only gets going in August the loss is considerably smaller.

It is important to know where the aphid gets the virus, and how the virus is kept going from year to year. In seed-growing areas the beet, because it is biennial, provides its own source : but in other areas it is believed that the aphids and the virus are carted into the clamps along with mangels and overwinter there. In the spring, from late March onwards, should any mangels be left, the aphids breed up on the infected shoots and carry the virus into the beet fields. Consequently this should be prevented by using an efficient aphicide, and if success is to be achieved against virus yellows this precaution must be universally taken. A useful measure where mangels are usually clamped with their tops on, is to clamp topped mangels only in one end of the clamp and to use these last, or such portion may be sprayed with a systemic insecticide before clamping.

Beet Eelworm (*Heterodera schachtii* Schmidt). Like all other cyst-forming root eelworms, this pest builds up its numbers during too close rotations not only of sugar beet and mangels but also of Brassicas, for these can act as hosts to this eelworm. Rotational precautions are provided for in the sugar-beet factory contracts that the farmer signs, and restrictions on Brassica growing have been recently tightened. Beet eelworm was first discovered in the east of England in the 1930's, and with the knowledge of what happened in Germany and also of the unrestricted spread of the potato root eelworm, legislation was at once enacted to prevent, or at least confine, the spread of the pest. All infected fields are scheduled under the Act, and the growing of plants of the beet family and the Brassica family is prohibited for as long as is deemed necessary in each case.

Other Pests. All the general soil pests, wireworm, leatherjackets, cutworms, and slugs will destroy young beet. The mangel flea beetle (*Chætocnema concinna* Marsh) in some years seriously delays the growth of the young seedlings, pitting the leaves in the characteristic flea beetle manner. Normally its host plants are in the dock family (*Polygonaceæ*) and the presence of fretted dock leaves gives added warning of its presence. Beet carrion beetle (*Acalypea opaca* L.) occasionally will destroy the foliage of young beet but recovery usually takes place. The larvæ are black and are reminiscent of wood lice. The pygmy mangel beetle (*Atomaria linearis* Steph.), formerly a destroyer of the germinating stages, is little heard of since the rotation clauses (preventing beet after beet or mangels) were put in the sugar beet growers' contracts.

PESTS OF BRASSICA CROPS

Brassicas in great variety occupy an important place among farm and market garden crops. They are attacked by flea beetles, stem weevil, gall weevil (Plates XXVII and XXVIII), swede midge, root flies, slugs, cutworms, caterpillars of cabbage butterflies and moths, mealy aphis (Plate XXIV), white fly and eelworms : the seed pods are attacked by pod weevil and pod midge.

Flea Beetles (*Phyllotreta* spp.) (Plate XXVII) are a serious pest of spring-sown seedlings of cabbage, kale, turnips and swedes. They are small dark inconspicuous beetles, in colour black, blue-black or bronze-black, sometimes with a yellow stripe down each wing case. Their hind-legs have thighs, or femora, enlarged for jumping. The beetles assemble about the seed rows and shelter in the soil when the weather is dull. They are active in sunshine and feed on the seed leaves, often completely devouring them or so crippling them that the plants fail to make normal growth. In a period of dry weather flea beetles may kill the seedlings of several successive sowings unless protective measures are taken.

Flea beetles lay yellow eggs in the soil near the seedlings, and the grubs devour root and stem tissue or burrow into the stems of lower leaves, the feeding-site and habits depending on the species of flea beetle. Pupation takes place in the soil, and beetles emerge during the summer and feed on the leaves of established Brassica crops and cruciferous weeds. Towards autumn they seek winter shelter in rough herbage, stack bottoms, hedge sides, and ditch sides, and in spring they leave these sites to feed on seedlings. Flea beetle injury is usually worst during the germinating stage. Beetles fly freely in bright weather and can travel some distance to food plants.

Control Measures. It is now possible to dress the seed with a concentrated gamma BHC seed dressing sold for the purpose, which should protect the early stages from attack. Should it be necessary a low-volume spray of DDT, or a dusting with powder containing DDT or BHC, will give complete control if properly applied. The dusts can be applied by means of insecticide dusters, powder blowers, adapted manure or seed drills and improvised shakers such as loosely woven bags. These dusts give good protection to the seedlings and a routine application will usually ensure a stand of seedlings from the first drilling. Similar aldrin and dieldrin formulations have also been developed.

Cutworms. Cutworms are the caterpillars of the turnip moth (*Agrotis segetum* Schiff.), heart and dart moth (*A. exclamationis* L.), and garden dart moth (*Euxoa nigricans* L.). The moths are dull, light or dark brown, with obscurely patterned wings and are often seen at haytime when grass is cut and turned. They are active only at night and hide during the day. They lay grey eggs in flat clusters on leaves, and after about a fortnight the caterpillars emerge to feed on foliage. As they get larger they become scattered and take to sheltering by day in the soil and coming to the surface at night to feed.

Cutworms are liable to attack the roots and stems of root crops and pretty well any other row crop, feeding at ground level and biting completely through the younger plants and excavating the root of the older ones. They will also eat into potato tubers. An examination at ground level of a wilting plant will usually discover one or more of the waxy-looking greyish caterpillars curved into half circles. There are two main phases of attack. The overwintering caterpillars feed on into late spring, when they attain a length of about 1½ in. The new generation occurs in June and early July and may do serious damage. Attacks often occur on land that has been weedy.

Control Measures. Cutworms can often be controlled by the Paris green-bran poison bait as recommended for leatherjackets (p. 430). This will have to be applied to the base of the plant when an attack is in progress. Quicker results can be obtained by the use of a DDT emulsion watered in at the base of the plant : or if land is known to be infested before planting, by working in a dust of DDT or BHC. A low-volume spray of aldrin could also be tried.

Mealy Cabbage Aphid (*Brevicoryne brassicae* L.). This grey aphid is probably most familiar to the farmer as a pest of swedes and these can be quickly ruined in epidemic years. The attack may be accompanied by mildew : the two troubles are often confused and it is important to distinguish them. All brassicas are attacked and Brussels sprouts are particularly vulnerable in that the aphids may get into the sprouts and are then difficult to reach even with a systemic spray. Attacks on swedes are easily controlled.

The aphid overwinters in the egg stage and in mild winter in the adult stage also : it builds up during spring on its host plants from which migration occurs from May onwards. Care should be taken that all field Brassicae whose useful life is over, such as old Brussels sprout crops, are well buried by this time. As summer proceeds, especially in a hot season, brassica crops should be watched for the beginnings of a build-up and a systemic insecticide applied as soon as the pest becomes threatening.

Cabbage Caterpillars. These are larvae of the Large White butterfly (*Pieris brassicae* L.), the Small White butterfly (*P. napi* L.) and the Cabbage Moth (*Mamestra brassicae* L.).

Large white caterpillars cause defoliation and occasionally in epidemic years whole fields are affected. Usually, however, the damage is confined to patches. There are two generations, early summer and late summer–early autumn : it is this second generation that does most damage. This generation is usually heavily parasitised by the Braconid *Apanteles glomeratus*, and groups of the deep yellow cocoons are a common sight in the autumn attached to the shrunken empty bodies of the caterpillars.

The small cabbage white butterfly lays single eggs which hatch into greenish caterpillars. DDT as dust and spray is quickly effective against these caterpillar attacks and derris can also be used if preferred. The cabbage moth lives in the heart of the cabbage and is more difficult to get at and needs early treatment.

PESTS OF PEAS AND BEANS

Black or Bean Aphid (*Aphis fabae* Scop.). This is one of the most serious pests of field and broad beans and has already been referred to as a pest of beet and mangels. A systemic spray can be used in the early stages, and since attack often begins around the headlands special attention should be paid to these.

Pea and Bean Weevils (*Sitona* spp.). Pea and bean weevils attack seedling peas and beans in early spring by eating semi-circular notches out of the leaves and stems. They may also be a serious bar to the establishment of lucerne and sometimes of clover. The commonest weevil (*Sitona lineata* L.) is brownish yellow or greyish yellow and covered with tiny scales forming light and dark bands down the elytra. The head is short and stout, the elbowed antennæ are brownish red, the eyes are dark and prominent and between them is a deep groove that extends to the short snout. The weevils may be seen pairing among pea and bean seedlings, but when disturbed they fall from the plants and lie motionless on the soil.

The eggs are laid in the soil. They are at first cream-coloured but become darker after two or three days: they hatch in about three weeks. The grub (Fig. 86) is white, wrinkled, and legless, with a brown head and strong biting jaws, and with fine bristles that assist movement through the soil. The grubs feed through the summer on roots, stem bases and root nodules of peas and beans, and their feeding shortens the life of the crop. In about two months the grubs cease feeding and burrow into firm soil to form earthen cells for pupation. The pupa is enclosed in a transparent membrane which leaves the limbs free. It is white at first, but it gradually darkens as it develops, and in two to three weeks the weevil is ready to escape. The new generation of weevils feed in late summer on the leaves of leguminous plants, and in autumn they seek shelter in stubbles, hollow stems and in dry rubbish.

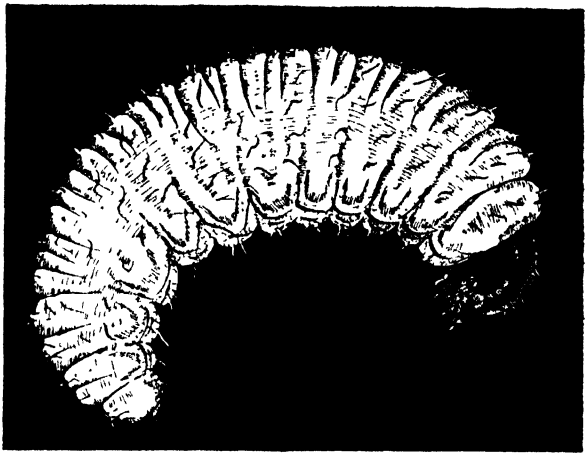

FIG. 86.—GRUB OF PEA AND BEAN WEEVIL (*Sitona*) : × 15.

Control Measures. Control of pea and bean weevils in market gardens can be readily secured by dusting in spring with DDT or BHC dusts at the rate of approximately 30–40 lb. per acre. The dust should have a heavy base so that it falls quickly on to the seedlings and does not blow about in a cloud. The protection afforded by a suitable insecticidal dust is soon apparent, and in the course of a few days dusted plants produce new leaves that remain uninjured. Field beans sown in autumn may be heavily attacked by the weevils before they seek winter shelter, but such crops are usually well established by spring and the stimulation to growth given by hoeing and cleaning is sufficient to enable them to withstand weevil injury.

Pea and Bean Beetles. Seeds of field beans, broad beans and occasionally peas, often have circular holes and cavities in the cotyledons. The holes are exit holes of small squat brownish grey beetles (*Bruchus* spp.) having short wing cases that leave the grey tip of the body exposed. The beetle, which is about ⅛ in. long, lays its eggs on the young bean pods. The grubs penetrate the pods and finally burrow into the developing seeds. They pupate inside the beans and the beetles are ready to escape about the time the beans are harvested. Some hibernate within the beans and others shelter in crevices about walls and floors of buildings and in the bark of trees. In spring the beetles frequent flowers and fruit blossom, and gradually assemble in bean fields for feeding and egg-laying.

Control Measures. Since injury by bean beetles seldom affects the embryonic region, the germinating capacity of bean seed is not seriously impaired by attack, but damaged seeds often rot in the ground and may be subject to infestation by secondary pests like millipedes. Modern methods of seed drying and seed fumigation are usually effective in destroying beetles hibernating in the beans. A light dusting with DDT or with BHC dust over the sacks, and over the floor and walls of barn or storehouse, will destroy beetles emerging in autumn from harvested beans.

Pea Moth. Late-sown peas and peas allowed to ripen before harvesting are often attacked by pea moth (*Cydia nigricana* F.). The moth has a wing expanse of about half an inch ; the fore-wings are dark brownish black with a satiny sheen and distinct white streaks on the front margin ; the hind-wings are lighter brown with a pale fringe. The flight period lasts from June to August and eggs are laid on leaves, stems and flowers of peas. The caterpillars tunnel into the pods and feed on the seeds, filling the pods with silk and excrement. When mature they are whitish and about half an inch long. They leave the pods and enter the soil to hibernate in cocoons of silk with adhering soil particles. Pupation takes place in spring and the moths emerge in summer. There is one generation a year.

Control Measures. The number of moths appears to fluctuate greatly, and the pest may be prevalent for several seasons and then become comparatively scarce. Crop rotation is a valuable method of limiting attack by pea moth on field peas, and carefully timed applications of DDT emulsion which aim at destroying the young caterpillars before they penetrate the pods, can be very effective : they keep down attacks by thrips as well.

Pea Eelworm (*Heterodera göttingiana* Lieb.) is an important pest of peas in market gardens. It feeds in the roots and forms cysts. Attack causes patches of dwarfed yellow plants which fail to set pods. Host plants of pea eelworm include peas, beans, clover and vetches, and the pest is associated with close cropping with these leguminous crops. Remedial measures consist of widening the rotation and improving the fertility of the soil so that susceptible crops are enabled to withstand some degree of attack.

PESTS OF POTATOES

Potato Root Eelworm (*Heterodera rostochiensis* Woll.) (Plate XXV) is associated with patchy failure in potato crops and occurs wherever close cropping with potatoes has been practised. The eelworms can be seen as white or yellow spherical cysts protruding from the roots and stolons (Fig. 87). Mature cysts are brown and may contain several hundred eggs and young eelworms. In the absence of their host plants the cysts remain viable in the soil for many years, but the presence of growing potatoes stimulates the hatching of eggs and the emergence of young eelworms. The eelworms invade the young roots and destroy the tips, and in consequence the plants suffer from malnutrition. Attacked plants are dwarfed and yellow and produce few tubers.

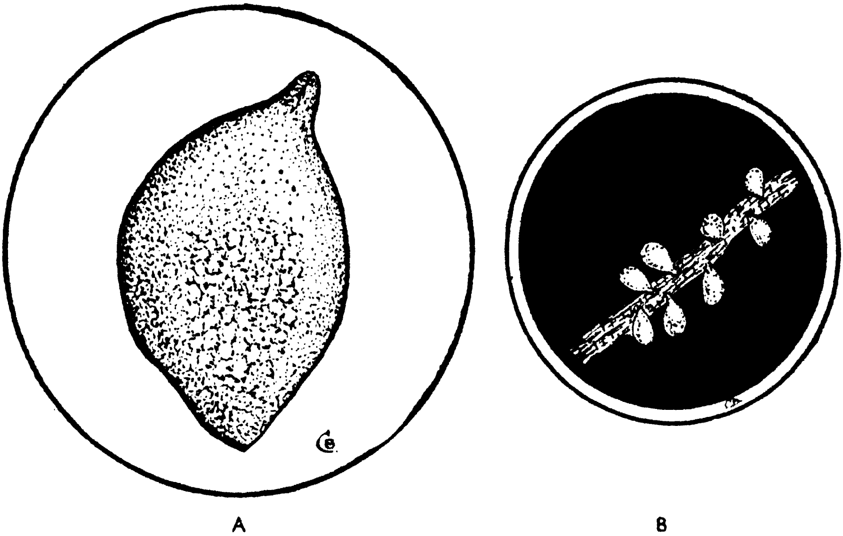

Fig. 87.—Root Eelworm (*Heterodera*).
A, cyst of beet eelworm : × 75.
B, cysts of pea eelworm protruding from root : × 8.

Once potato root eelworm is established in fields intensively cropped with potatoes its multiplication is rapid and yields of tubers are greatly reduced. The greatest source of infestation is the soil adhering to seed potato tubers and in the bottom of sacks and containers. Control by soil treatment has not proved satisfactory. A rigid insistence on a wide rotation will prevent the establishment of potato root eelworm and will reduce the loss from the pest in fields where it is already established.

Colorado Beetle (*Leptinotarsa decemlineata* Say.). Colorado beetle was introduced into Europe from America late in the nineteenth century. It has gained entry to Britain several times but owing to a good system of inspection and the use of effective control measures, every outbreak has been promptly eradicated. The beetle is rather rounded, about two-fifths of an inch long. In colour it is yellow with four back stripes extending lengthwise along each wing cover, and there are black markings on the thorax. The beetles hibernate in the soil, often at a depth of 10–12 in., and emerge in early summer. They walk or fly to potatoes where they feed on the foliage and lay clusters of upright yellow or orange-yellow eggs. The eggs hatch in ten to fourteen days and the little dark-coloured grubs resemble the grubs of ladybird beetles. At first the grubs feed in colonies on the leaves but as they get older they become dispersed over the plant. Colorado beetle grubs are fully fed in about three weeks and by that time they have eaten the leaflets to the midrib and have fouled many leaves with excrement. Mature grubs are about half an inch long, rather humped and swollen, and reddish with head and legs black and two rows of black spots along the sides. They penetrate to a depth of 2–3 in. in the soil for pupation, and in less than a fortnight, in late July or early August, the new generation of beetles emerges. These beetles feed locally on potato foliage and may migrate by flying to another crop before returning to the soil to hibernate. In recent years there have been no outbreaks and this is partly due to precautionary measures taken on the nearest Continental coasts.

Control Measures. In Britain control of Colorado beetle is the responsibility of the Ministry of Agriculture, to whom any outbreak must be promptly reported. Inspection of potato crops in suspected areas is now a routine practice, and when outbreaks occur infested crops are sprayed with arsenical or other approved insecticides and the soil is fumigated with carbon bisulphide under strict official supervision.

Potato Aphids. At least four aphids commonly infest the potato, but though they can sometimes cause much direct harm their importance lies in the fact that one of their number, the peach-potato aphid (*Myzus persicæ* Sulz.), is mainly responsible for spreading the virus of leaf-roll in potato stocks. Because of this, new seed has continually to be imported into the ware growing districts from the relatively aphid-free areas, thus adding to the expense of growing the crop.

PESTS OF GRASS AND CLOVER

Grasses are related to cereals and are subject to attacks by many of the pests of cereals. Rye grass is attacked by maggots of frit fly and the grass aphids may occasionally devastate a seed crop or ley. Midges infest grasses and the flower heads are often distorted through their attacks ; the foxtail midges prevent the formation of seed in meadow foxtail grass. The cocksfoot moth (*Glyphipteryx fischeriella* Zeller) feeds on the seed of cocksfoot grass.

Leatherjackets and chafer grubs are pests of old grassland. Leatherjackets tend to occur in damp, chafer grubs in drier, situations, e.g. on the thin soils of hill and mountain slopes, and in the dry and cold sandy pastures of the Midlands and East Anglia.

Chafer Beetles. Three species of chafer beetles are common in Britain. The cockchafer (*Melolontha vulgaris* F.) is about 1¼ in. long with the head black, the prothorax covered with long greyish hairs, and the elytra light chestnut brown and distinctly ridged. Antennæ and legs are brownish ; the apex of the abdomen is exposed and tapers to a broad down-turned tip. The garden chafer (*Phyllopertha horticola* L.) is about half an inch long with the prothorax a dark metallic green or blue and the elytra brown ; the long legs and the tips of the antennæ are black. The summer chafer (*Amphimallus solstitialis* Latr.) is about ¾ in. long ; the prothorax and elytra are yellowish brown and the elytra have indistinct ridges that suggest stripes. The cockchafer flies at night in May and June and rests by day among the foliage and blossoms of trees. The garden chafer flies in bright sunshine in May and June and hides in grass and vegetation at night and in dull weather. The summer chafer flies in late evening in the latter part of June and the beetles often swarm about high trees in grass country. The grubs of all three species live in the soil. The garden chafer reaches maturity in one year and the cockchafer takes three to four years to complete its life cycle. The summer chafer and the garden chafer are largely grassland insects but the cockchafer is most abundant in areas of mingled woodland and pasture.

Remedial measures against chafers and leatherjackets are similar. They consist of breaking the old matted turf, correcting any mineral or lime deficiency, and re-seeding with a suitable grass mixture. Birds are fond of chafer grubs and feed regularly in infested fields.

Young clovers are attacked by pests of peas and beans (see p. 406). Pea and bean weevils (*Sitona* spp.) devour stems and leaves and are sometimes responsible for the poor take of clover in young leys. Clover leaves are also attacked by several species of leaf-eating sawflies including *Pteronidea myosotidis* F. Clover for seed is often infested by seed weevils (*Apion* spp.), small black pear-shaped weevils whose grubs feed in the seed heads and reduce the yield and quality of the crop.

Stem and Bulb Eelworm (*Ditylenchus dipsaci* Kuhn) is by far the most important pest of clover. It contributes to " clover sickness ", a name for the repeated failure of red clovers on old arable land. The eelworms (Fig. 88) are present in the soil when the seed mixture is sown and they penetrate the seedlings soon after germination. Infested seedlings become swollen and distorted and many are killed. Red clovers are susceptible to attack and there is a high mortality among seedlings sown in eelworm-infested soil ; late-flowering red clovers and alsike are fairly resistant, and white clovers and hop-trefoil are almost immune. In arable districts where red clovers regularly die out of the leys, seed mixtures should contain the resistant types with rye grass, cocksfoot and timothy. Stem eelworm is spread in hay from infested pastures, in fragments of infested plant tissue, in seeds from infested crops and in the soil on implements and on the hoofs of livestock. The diagnosis of eelworm disease is difficult and technical help should always be sought when the presence of eelworms is suspected. It may be confused with the disease brought about by the clover rot fungus described on pages 346–347.

PESTS OF VEGETABLES

Vegetable crops suffer from attack by numerous pests including cabbage white butterflies, cabbage moth, garden pebble moth, angle shades moth, asparagus beetle, celery leaf miner, turnip gall weevil and many aphides. Two fly pests are of special importance, cabbage root fly and carrot fly.

Cabbage Root Fly (*Erioischia brassicæ* Bouché) is an Anthomyid fly somewhat resembling a housefly. The flies emerge from overwintering pupæ in April and early May and lay white eggs in the surface soil close to the stems of seedling Brassicas and transplanted cauliflowers and cabbage. The eggs hatch in four to five days and the maggots feed on the surface tissue of the rootstock and lower part of the stem. Rotting frequently accompanies attack by root maggots and the plants may be killed or their growth may be severely checked. The maggots reach maturity in about three weeks and become puparia in the soil in the vicinity of the plants. The puparia are reddish-brown, barrel-shaped and about the size of a grain of wheat. Flies emerge from most of the summer puparia in two to five weeks, but occasionally emergence is delayed for several months. There are two or three generations a year. No cruciferous crop is free from attack by root maggots ; wallflowers, radishes, kales, swedes and young brussels sprouts may be infested.

Control Measures. The former use of calomel is now justified only if the disease club-root has to be dealt with as well, because cheaper and more efficient control is now possible with either BHC or dieldrin. Spot application at the " collar " in dust or liquid (wettable powder, emulsion) form is best, though some protection is given by dipping, a labour-saving substitute preferred by growers. Seed-bed protection is also possible by spraying.

The Carrot Fly (*Psila rosæ* F.) appears early in May, and after feeding in flowers of wild Umbelliferæ it flies to young carrots for egg-laying. The eggs are laid in the soil near carrots and the slender white maggots burrow into the tap roots near the tips. Attack results in a check to growth and the foliage flags and loses its fresh green colour. In some plants the root tips are severely tunnelled or destroyed, and the tap roots may become forked or distorted (Plate XXVIII). Maggots of carrot fly reach maturity in about four weeks and become puparia in the soil. In July and August there is a second generation of flies. These give rise to maggots that continue feeding during autumn in maincrop carrots, celery, parsnips and parsley. Flies often congregate in May in hedgerows and were formerly attacked there with a 0·5 per cent DDT spray. This method was superseded by BHC seed dressing which provided a complete answer to first generation attack. A dieldrin formulation was later introduced. If necessary, sprays may be used against the second generation attack but used with caution to avoid contamination.

PESTS OF GRAIN AND FEEDING-STUFFS

Grain for seed or for feeding, peas and beans, flour, meal and cattle cake that have to be stored for some time often deteriorate through infestation with insects and mites. Beetles, weevils, caterpillars and mites are common about farm granaries and food stores, and care must be exercised to restrict their numbers and to protect the stored food.

Granary Weevil (*Calandra granaria* L.). This beetle is about ⅛ in. long and dark brown, with elbowed antennæ that originate near the base of the snout, a long coarsely punctured thorax, and elytra with longitudinal grooves and ridges. The eggs are laid in holes bitten in the grain and the soft yellowish-white, legless grubs feed inside the grain. The pupa is formed within the grain and the adults emerge in six to nine days. The life cycle is completed in four to six weeks and, when temperature and humidity are suitable, generations of weevils follow each other quickly and grain soon becomes heavily infested.

Moths. Several species of moths infest farm granaries but the most common are the brown house moth (*Borkhausenia pseudospretella* Staint.) and the white-shouldered house moth (*Endrosis lactella* Schiff.). The brown house moth has a wing expanse of about ¾ in.; the head and thorax are light brown, and the fore-wings light or dark brown with three distinct dark areas that look like three pairs of black spots when the moth is at rest; the hind wings are light grey. The white-shouldered house moth has the head and thorax conspicuously white, the fore-wings yellowish-grey speckled with black and white, and the hind-wings pearly grey with a deep fringe of light hairs. Both species lay eggs on almost any kind of stored food and the caterpillars spin silk in which frass, or pellets of excrement, become entangled. When fully grown the caterpillars are about half an inch long, white with the head brown, and with conspicuous brown plates on the thorax just behind the head; stoutish bristles are sparsely scattered over the body. The larvæ spin tough silken cocoons in cracks and crevices in bins, about the walls, floors and beams of granaries and store-rooms, and in sacks and sacking. There are several generations a year. Infested food in bins and sacks becomes fouled by the silk and frass of the caterpillars and the wastage is considerable.

Flour Mites. Several species of flour mites (Tyroglyphidæ) infest food stores. They are minute creatures, pale grey or whitish in colour, and when numerous they resemble flour dust. Examination with a lens shows that mites have eight legs, a short pointed head and a rounded oval body bearing a number of rather long hairs or setæ. Mites are able to eat holes in cereal grains, and infested corn soon develops an unpleasant musty smell. The life cycle of mites is completed in about three weeks and breeding goes on practically all the year round.

Other pests about farm buildings and food stores include the larder beetle (*Dermestes lardarius* L.), the cheese and bacon fly (*Piophila casei* L.) and the meal worm (*Tenebrio molitor* L.).

Control Measures. Control of pests of stored foods is largely a matter of granary hygiene. Walls, floors and roofs should be properly cleaned before fresh stores are brought in. Walls and stone floors should be faced with cement to reduce shelter and wooden floors should be sealed with a bitumastic preparation. Bins and other receptacles should be kept clean and empty sacks should be removed and sterilized before using them again. Light applications of insecticides like BHC, DDT and malathion to walls and floors of storerooms before taking in fresh consignments of food are also helpful in keeping down pests, as are insecticidal " smokes ".

PESTS OF LIVESTOCK

Insect and allied pests of livestock cause appreciable losses to British farmers. Biting flies make dairy herds restless and irritable during milking ; the proximity of blood-sucking and warble flies causes gadding and stampeding and the tormented herds soon lose condition ; infestation by lice, fleas and ticks checks the growth of young animals and may infect them with diseases and worm parasites ; and the attacks of parasitic flies on sheep and cattle may bring about internal disorders that result in death. Much research has been carried out on the pests of livestock during recent years, and investigations on the properties of pyrethrum and derris and, later, on DDT and BHC have led to improvements in the control measures. In the following pages the present knowledge of the life histories and habits of common pests of farm livestock and the means of controlling them is summarised ; but future extensions of the livestock industry are likely to be followed by further developments in the protection of flocks and herds, and the student should read farming papers for new and up-to-date information on insecticides and methods of using them.

Warble Flies. Cattle are attacked by two species of warble flies : *Hypoderma bovis* de G. and *H. lineatum* Vill. They are on the wing in spring and summer and lay eggs on the under parts and legs of the animals. The larger species, *H. bovis*, lays eggs singly and the smaller, *H. lineatum,* lays them in rows on hairs low down on the legs. Warble fly eggs are yellow and are attached to the hair by short clasp-like extensions of the base (Fig. 88, B). They hatch in three to six days, and the maggots burrow into the skin at the bases of the hairs and cause swelling and inflammation. Maggots of *H. bovis* travel to the backs of their hosts through the connective tissue under the skin, and frequently they enter the spinal canal. Maggots of *H. lineatum* burrow in the connective tissue to the gullet, which they reach when they are about half-grown, and from the gullet they migrate to the back. The warble maggots reach the back from February onwards ; they perforate the hide in order to breathe and remain stationary in pus-filled cavities. The swellings made by the maggots are about the size of a walnut and can be easily felt by running the hand along the back from withers to tail. The maggots attain a length of 16–26 mm. (from two-thirds to just over an inch), and are dull yellow or cream-coloured (Fig. 88, C) and much wrinkled. By April they begin to reach maturity. The fully developed maggots enlarge the breathing pores, escape through the hide and fall to the ground to pupate. The pupal stage lasts five to six weeks. The emergence of the bee-like adults completes a life cycle lasting about a year, of which ten to eleven months are spent feeding within the bodies of the hosts.

Warble flies on the wing make a buzzing sound that causes the cattle to run wildly about the fields, and in consequence they lose condition rapidly. The passage of the maggots through the body tissues, the gullet and the spinal canal, and their establishment in the back, causes great irritation and inflammation which further contribute to loss of health and vigour in infested animals. Attack by warbles also reduces the value of the hides because perforations made by the maggots persist in the leather and entail much waste when it is used.

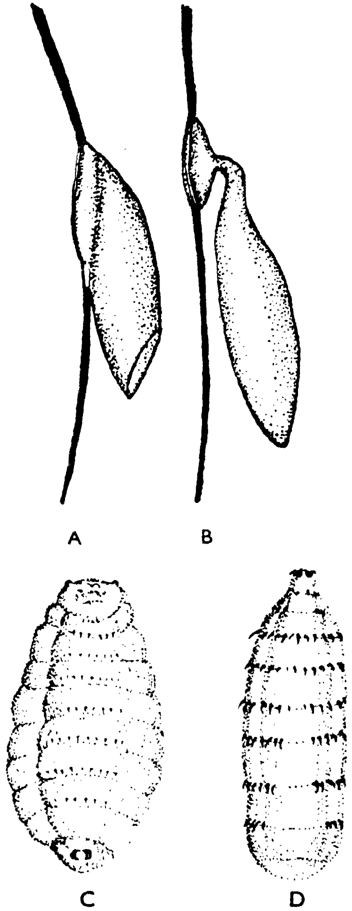

FIG. 88.—EGGS AND MAGGOTS OF WARBLE FLY AND BOT FLY.
B, egg; C, maggot of Ox Warble. A, egg; D, maggot of Horse Bot.
(Eggs: × 26; maggots: × 2.)

Control Measures. After detailed studies of the distribution of warble flies in Britain the Ministry of Agriculture and Fisheries introduced the Warble Fly (Dressing of Cattle) Order in 1936, which made it the responsibility of stock owners to destroy the maggots or warbles in cattle that were visibly affected. Approved dressings contained the equivalent of ½ oz. rotenone (the active principle in derris root) per gallon, and usually consisted of 1 lb. derris and ¼ lb. soap per gallon of soft water. The dressing had to be applied to the backs of infested animals at monthly intervals from 15th March to 30th June. An alternative treatment was the removal of warbles, by squeezing or other means, at ten-day intervals during the same period.

Since cattle are the only hosts of the ox warble flies the enforcement of the order requiring the destruction of warbles in infested cattle had secured an appreciable reduction in the severity of warble fly attack by 1940, when lack of derris led to its suspension. Dressing of visibly affected animals has again been made compulsory by the Warble Fly (Dressing of Cattle) Order, 1948. Insecticidal dressings should be applied with a stiff brush that exposes the warble pores, or they should be swabbed on the backs of the animals with a cloth in such a way that they penetrate the breathing pores and reach the warbles. If control measures were carefully and consistently applied by all stock men, warble flies would ultimately be eradicated. This desirable position may be brought nearer fulfilment with the use of the recently introduced organophosphorous compounds which can be administered either orally or applied to the back as with derris. The advance here is that a *single* dressing appears effective.

Sheep Nostril Fly. The sheep nostril fly, *Œstrus ovis* L., is a yellowish-brown, bee-like fly related to the warble flies. It is active in hot summer weather, and deposits eggs or young maggots in the nostrils of sheep. The maggots are spiny and easily work their way through the nostrils into the nasal cavities, and finally into the frontal sinuses of the head where they attach themselves to the mucous membrane. Their feeding causes irritation and inflammation in the head, and when the brain becomes affected the sheep appear dazed, a condition called " false gid " or " false sturdy " to distinguish it from a similar condition produced by the larval stage of the tapeworm, *Tænia multiceps* Leske. The maggots of the nostril fly remain in the frontal sinuses for about ten months and attain a length of about an inch. When mature they detach themselves from the mucous membrane and are sneezed out on the soil, into which they burrow for pupation. The life cycle is completed in about a year.

Control Measures. Sheep nostril fly is difficult to control, but the provision of shade for the animals and the use of repellent smears containing tar or creosote are recommended for reducing attack. The smears can be renewed automatically if lids of salt troughs have holes through which the sheep thrust their noses to reach the salt, and the edges of the holes are kept well coated with smear. Examination of slaughtered sheep has shown that the presence of a few maggots of sheep nostril fly does not seriously affect the condition of the sheep, but when upwards of a score of maggots occur the sheep are visibly affected. When sheep are obviously distressed and attack by sheep nostril fly is suspected, the advice of a veterinary surgeon should be sought.

Horse Bot Fly. The horse bot fly, *Gasterophilus intestinalis* de G., another relative of the warble flies, is a large, brown, hairy fly somewhat like a honey bee in appearance. It lays elongate yellowish-white eggs (Fig. 88, A) and attaches them to hairs, usually on the fore-legs within reach of the horse's tongue, but occasionally on the shoulders, parts of the belly and the hind-legs. It appears to be an advantage to the species that the eggs are laid on parts of the body that can be licked. Friction from the lips helps the eggs to hatch, and the young maggots are licked into the mouth. They burrow under the tongue and in due course make their way through the gullet to the stomach, where they attach themselves by their mouth hooks and remain for nine to ten months obtaining nourishment from the stomach contents. When mature they are over half an inch long, rather barrel-shaped, and with girdles of short, chitinous, backwardly directed spines on the body segments (Fig. 88, D). They leave the host with the fæces and enter the soil for pupation. The pupal stage lasts about a month and the flies emerge in the later part of summer.

Control Measures. Effective control of horse bot flies is difficult. Clipping the hair on the legs and under parts and rubbing down the animals with mild disinfectants, or with a little derris extract on a damp cloth, help to prevent infestation. The provision of shade permits the animals to escape from the attentions of these sun-loving flies during the egg-laying period. Carbon bisulphide capsules have been used against bots with some success, and where there is reason to suspect a heavy infestation a veterinary surgeon should be consulted as to the advisability of using the capsules or some other approved drug to evacuate the maggots.

Gadflies and Clegs. Gadflies and clegs belong to a family of flies (Tabanidæ) in which the females suck blood to nourish their eggs. In Britain three groups are troublesome to farm animals, and they can be distinguished by their colour and wing patterns. Gadflies (*Tabanus*) are large dark flies with clear wings (Plate XXI, B). Breeze flies (*Chrysops*) are dark with conspicuous triangular yellow marks on the upper surface of the abdomen, and the wings have a broad dark band across the middle and a less distinct band near the tip (Fig. 89). Clegs (*Hæmatopota*) are ashy-grey with the entire surface of the wings finely mottled. Flies in all the groups have large brilliant eyes, often banded or spotted, and short, stout head-feelers, and they are able to travel long distances in search of a meal of blood. They are on the wing in bright sunshine from May to September, and animals in open low-lying situations and about the edges of woodlands are especially liable to attack.

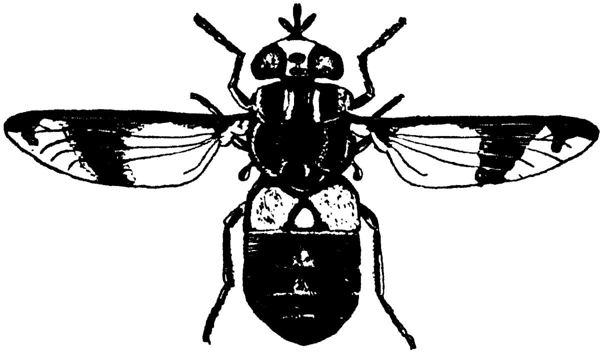

FIG. 89.—BREEZE FLY (*Chrysops cæcutiens* ♀) : × 3.

Females of these blood-sucking flies lay eggs in masses on the leaves and stems of water plants and on sticks and posts projecting from ponds, pools, ditches, lakes and shallow sluggish water courses. The newly hatched maggots fall into the water and burrow in the mud at the bottom, where for two years they feed on small insects, worms and other soft-bodied animals. When they have finished feeding they seek drier soil beyond the swampy margin of the water, and pupate at a depth of about an inch. The pupæ have a thin brown skin with rows of bristles on the segments, and the developing fly is visible within. At emergence the pupal case is left behind in the soil and the fly crawls to the surface to expand and dry its wings.

Control Measures. No methods of controlling gadflies, clegs and breeze flies have yet been devised. The breeding grounds in swamps and the bottoms of shallow lakes, ponds and ditches are difficult to treat, but draining and reclaiming damp low-lying land and keeping water courses clean and open limits the extent of suitable feeding-sites for the maggots. Since blood-sucking flies are most active in bright sunshine in the middle of the day the provision of dense shade by means of trees or sheds gives some protection from attack. Horses at work should be protected by coarse cord netting slung over the neck and back ; the constant movement of the net disturbs the flies and reduces their opportunities for biting. Repellent dressings containing carbolic acid tend to keep the flies away, and horses can be rubbed down lightly with a pad or cloth damped in a solution of 1 part carbolic to 5 parts water.

Biting Midges and Black Flies. Females of biting midges (*Culicoides*) and black flies (*Simulium*) suck the blood of man and animals, and are especially annoying to farm animals when they bite the tender tissue about the eyes, mouth, nose and ears. Biting midges are exceedingly common over most of Britain. They are tiny, greyish, two-winged flies that appear in swarms at dawn and dusk and on dull damp days in summer. Their bites cause inflammation. *Culicoides impunctatus* Meig. is a common and troublesome species and *Culicoides nubeculosus* Meig. transmits parasitic worms to horses. Biting midges breed in damp soil, in shallow standing water and in moisture in holes in trees, and are active from spring until autumn.

Black flies are larger than the biting midges and inflict severe and painful bites. They are usually about ⅛ in. long, dark coloured, stoutly built and somewhat hump-backed ; one of the larger species, *Simulium ornatum* Meig., the ornate black fly, is black with light markings on the thorax, abdomen and legs. Black flies are less well known than biting midges, but they can be recognised by their curious direct and darting flight. They occur in open and wooded country but are seldom found in stables and cowsheds. They breed in swift-flowing rivers and streams, and the maggots anchor themselves to stones and rocks by means of sucker-like discs and hooks at the tip of the body, and feed on animalculæ that are caught in the head fans. Pupation takes place under water, and at emergence the fly floats in an air bubble to the surface from which it takes flight immediately. The life cycle takes ten to twelve weeks in summer and there are two or more generations a year. The flies are sometimes found about fruit blossom, and are on the wing periodically during summer and autumn.

Control Measures. Control of biting midges and black flies presents a serious regional problem whose solution appears to lie in the widespread treatment of the major breeding-sites. The damp soil at the edges of ponds and streams and swampy upland pastures might be treated with soil insecticides, and the streams in which black flies breed might be treated with miscible oil. Since regional control of these pests has not yet been attempted in Britain, and the suitability of DDT and similar insecticides has not been fully investigated, the use of repellents should be continued. Repellents based on di-methyl-phthalate (DMP) are available.

Sheep Maggot Fly. Sheep maggot flies or green bottles and blue bottles, of which *Lucilia sericata* Meig. is the most important, are carrion feeders and scavengers, but they also lay eggs in wounds and in the hind-quarters of sheep, and the resulting maggots tunnel into the flesh and give rise to the condition known as " strike ". When neglected, the fly-struck sheep rapidly lose condition and stray away from the flock and die. Sheep maggot flies have a short life cycle and several generations occur during spring, summer and autumn. The eggs hatch a few hours after being laid and the maggots become fully grown in two to three days. Pupation takes place in the soil. The flies emerge in about three weeks and are active in sunshine, especially when the atmosphere is damp and sultry.

The condition of the fleece has an important influence on the occurrence of " strike ". The flies are attracted to wool contaminated with fæces and urine, and in consequence strikes are most frequent about the hind-quarters. In showery weather when the fleece is kept moist by rain and wet vegetation and has a high bacterial count, the risks of sheep becoming fly-struck are much greater than in dry weather. In normal healthy sheep the temperature near the skin is too high, and the humidity too low, for the maggots to survive, but any factors altering these conditions favour the development of the pests. Two breeds of sheep, the Wiltshire and the Shetland, appear to possess high resistance to sheep maggots ; but in most breeds some sheep are more susceptible to attack than others, and in many flocks the same sheep are fly-struck repeatedly year after year while they remain in the flock.

Control Measures. The introduction of dips containing DDT, or both DDT and BHC, and more recently dieldrin, has during the last eight or nine years very greatly reduced the incidence of blowfly strike in sheep. A great advantage which these new insecticidal materials possess over the arsenical and other compounds previously used in dips is their persistence in an active state for quite long periods. After dipping, enough of the insecticide remains on the wool either to kill the flies that alight there or so to upset them that they are unable to deposit their eggs, and this may combine to give protection for four or six weeks. Spraying is sometimes substituted for dipping. Crutching the sheep also helps to reduce troubles caused by maggot flies.

The treatment for fly-struck sheep consists of clipping the wool from maggot-infested areas and applying a dressing to kill the maggots and heal the wounds. Effective modern dressings are on the market.

When sheep die from strike or other causes the carcasses should be thickly dusted with dieldrin before burial in order to destroy developing maggots. Ground about permanent sheep folds and dipping baths often harbours maggots and chrysalids of sheep flies, and should be cleaned periodically by ploughing and by dusting or spraying with soil insecticides. Regular cutting or burning of bracken and scrub on sheep pastures helps to maintain dry conditions for the flock, and reduces shelter for the flies.

Stable Fly. The stable fly, *Stomoxys calcitrans* L. (Fig. 90), is a greyish fly about the same size as a house fly, and its stiff projecting proboscis (Fig. 91), divergent wings and abdomen with dark spots make it easy to recognise. Like the house fly it breeds in rotting vegetation and dung, and thrives best in the drier parts of manure heaps containing cow dung. The flies frequent cowsheds and stables, gate-posts of pastures and trunks of trees near drinking-places. The females require several meals of blood before the eggs are mature, and they obtain the blood from cattle, horses, pigs and man. Each female is capable of laying upwards of 500 eggs in small batches in the moist crevices of manure heaps. The life cycle takes about six

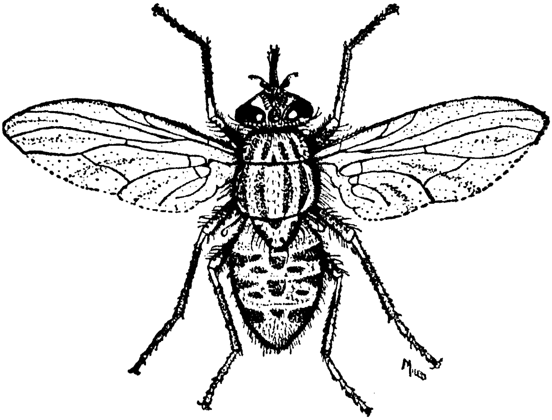

FIG. 90.—STABLE FLY (*Stomoxys calcitrans* ♀) : × 5.

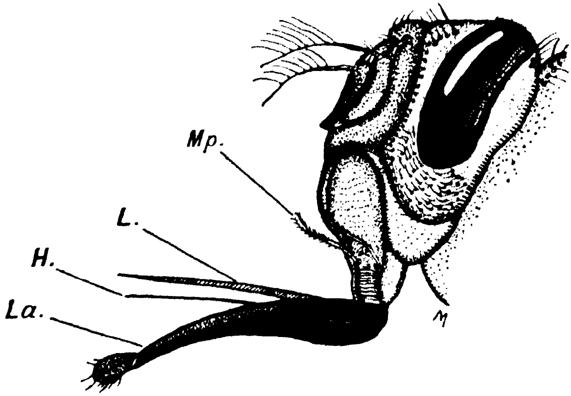

FIG. 91.—HEAD OF STABLE FLY TO SHOW PIERCING MECHANISM.
Mp., maxilliary palp ; L., labrum ; H., hypopharynx ; La., labium. × 20

weeks and there are several generations during the year. The flies are on the wing from spring to autumn and are most abundant in July, August and September. They are a special nuisance to dairy herds. They follow the cows into the byres and milking-sheds, and by their persistent biting of the legs of the animals they cause the stamping, kicking and restlessness during milking that is characteristic on infested farms.

Control Measures. When the cattle leave the milking sheds the stable flies remain behind on the walls, ceilings, rafters and pillars, and out of doors they bask on sunny walls and doors. A proportion of such resting places may be sprayed with DDT or malathion but the surface should first be rendered non-absorbent. Special insecticide-containing paints and synthetic resins are also available. Incoming cows can be cleared of their fly ' load ' in enclosed collecting points with pyrethrum aerosols. Malathion is applied directly on cattle in the U.S.A. but recently attention has been directed to two other organophosphorus compounds, dichlorphon and fenchlorphos. The first is very effective as a fly ' varnish ' bait, the second is used on cattle 'rubs'. Finally, much can be done to prevent or reduce breeding in manure heaps by general hygiene and the use of insecticides. It should be remembered that resistant fly strains can be developed by the constant use of the same insecticide and there should be a change about from time to time.

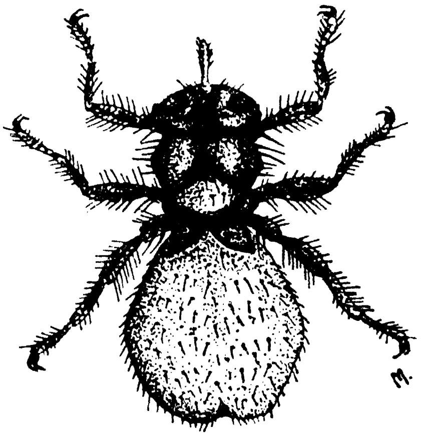

FIG. 92.—SHEEP KED (*Melophagus ovinus* ♀) : × 8.

Sheep Ked. The sheep ked, *Melophagus ovinus* L., is a curious flat hairy, brown, wingless fly about ¼ in. long (Fig. 92). The head is closely joined to the thorax, and has distinct eyes and a long proboscis armed with spines that assist in penetrating the host ; the thorax has neither wings nor halteres, but has powerful hairy legs with long tarsal claws to enable the ked to maintain its hold on the sheep, and the abdomen is sac-like. Keds of both sexes feed on the blood of sheep and occasionally goats, and twenty-four hours' sucking may be required to obtain a full meal. Reproduction is by means of eggs that mature singly. Incubation takes place in the body of the female and the larva is nourished there until it is fully grown. At intervals of seven to ten days throughout the summer a fully fed larva is extruded. It sticks to the wool and becomes a pupa without feeding, and the adult emerges in three to four weeks. Females of the new generation produce their first fully developed larva about two weeks after they emerge, and though each female produces only 10–15 larvæ the progeny of one pair may total some hundreds in the course of the season.

The movement of keds over the skin of infested sheep causes constant irritation, and when the parasites are numerous the sheep become unthrifty. Keds migrate from sheep to sheep, and from sheep to lambs, during the flocking operations incidental to management, but a dip containing dieldrin as used for the control of sheep maggot flies (p. 449) gives satisfactory control of the pest.

Fleas. Fleas (Aphaniptera) are small brown wingless insects, characteristically flattened laterally ; they have long hind-legs adapted for jumping, and piercing mouth structures with which they puncture the skin of their warm-blooded hosts and suck the blood. The narrow body clothed with backward-pointing bristles, and the long powerful hind legs, enable fleas to move rapidly among the hair or feathers of their hosts, and give them some protection against rubbing and scratching. Fleas occur on most small rodents, dogs, cats, rabbits, birds and poultry. Rat fleas are of special importance because they frequently attack other animals and man and spread a fatal disease called bubonic plague. Other species of fleas transmit tapeworms in dogs and children. The irritation caused by the feeding of numbers of fleas soon lowers the condition of animals and makes them restless and unthrifty.

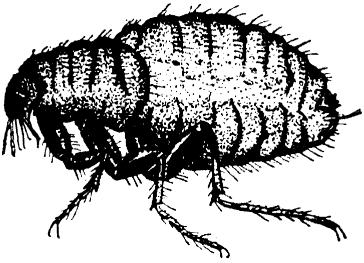
FIG. 93.—DOG FLEA (*Ctenocephalus canis* ♀) : × 15.

Two species of fleas common about farms are the dog flea, *Ctenocephalus canis* Curt., and the hen flea, *Ceratophyllus gallineæ* Schrank. The adults live mainly on the bodies of the hosts, though they often occur about the sleeping-quarters. They feed frequently and draw relatively large quantities of blood, some of which is voided in a partly-digested form that can be found as small dry pellets on the hosts, about nest boxes and in places where dogs sleep. The females lay white eggs in the fur, hair or feathers of the hosts, and the eggs fall or are shaken out into the bedding or nest-box material. They hatch into active white maggots with brown heads, and the maggots move freely by means of bristles : they bear a close resemblance to the grubs of small carabid beetles. They feed upon waste skin cells, feather base scales and organic particles in dust, and upon the dry blood-containing excrement of the adults. They reach maturity in two to three weeks and pupate in cocoon-like cases. New adults emerge in a few days and the complete life cycle from egg to adult requires only about three weeks. Under some conditions the adults remain dormant in the cocoons for a long period and emerge when there is some marked change in the environment ; this phenomenon sometimes accounts for the sudden emergence of large numbers of fleas in unexpected places. Frequently cocoons and fully fed maggots fall through floor crevices and accumulate in the debris under kennels, hen houses and rabbit hutches.

Control Measures. It is obvious from a knowledge of the life history and habits of fleas that hygiene plays an important part in their control. Clean bedding frequently changed, the treatment of bedding, nest boxes and dust baths with pyrethrum, derris, lonchocarpus, DDT or malathion, and the occasional application of these insecticides as dusts on animals and poultry keep the flea population at a minimum. Floors and walls of hen houses and kennels may be sprayed or dressed with light creosote, or the interior of hen houses may be treated with DDT, BHC or malathion.

Biting Lice and Sucking Lice. Biting lice and sucking lice belong to the Order Anoplura, and are wingless degenerate Exopterygota (see p. 410) that spend their whole lives on their hosts and soon die if they are removed from the warmth and shelter of the hosts' bodies. The biting lice (Mallophaga) have broad heads and mandibulate mouths, and are found most generally on birds though some species occur on farm animals and dogs. The common biting louse of the dog is *Trichodectes canis* Deg., a broad yellowish species that multiplies rapidly on neglected animals and is known to transmit tapeworms. A common and injurious louse of poultry is *Menopon gallinae.* (Fig. 94, A), an active insect with four-segmented antennæ, that crawls readily on the hands and arms of persons handling infested birds. Biting lice feed on fragments of dead skin, hair, fur and feathers, which they bite off with their sharp mandibles. The sucking lice (Siphunculata) have narrow heads and mouth parts adapted for piercing and sucking. A number of species infest farm animals. The pig louse, *Hæmatopinus suis* L. (Fig. 94, B), attacks pigs about the neck and jowl, the bases and insides of the ears, the belly and the inner sides of the legs. A smaller species of *Hæmatopinus* feeds on cattle about the shoulders, neck, forehead, escutcheon and base of the tail, and other species attack horses and sheep. The sucking lice have large curved tarsal claws with which they maintain their hold on the hosts.

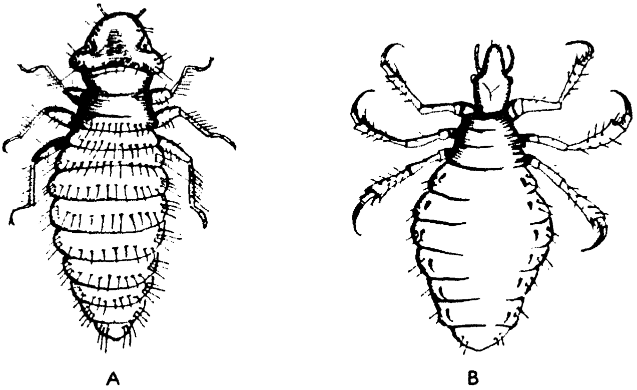

Fig. 94.—Lice.

A, biting louse of poultry (*Menopon pallidum*) : × 15.
B, sucking louse of pig (*Hæmatopinus suis*) : × 10.

The eggs of lice are laid singly and stuck to hair, fur or feathers of the hosts ; they are easily seen with the unaided eye, and are well known as " nits ". They hatch in four to five days and the empty egg shells remain attached to the host for long periods. The young lice resemble the adults in appearance and feed in the same manner. Lice are spread when their hosts are in contact with each other, and the biting and sucking and scratching with their long sharp claws as they wander about the hosts causes great discomfort and irritation. Infested birds and animals take little food or rest and their health soon deteriorates. Lice transmit disease, the body louse of man being notorious as the carrier of typhus fever.

Control Measures. Animals infested with lice do much rubbing and scratching and the irritation is followed by dullness of coat, falling hair and bare patches. The presence of numbers of lice among farm stock and poultry necessitates the thorough cleaning and disinfecting of their quarters : sties, byres, sheds, loose boxes and poultry houses. Woodwork may be treated with insecticidal wash, but the main effort should naturally be concentrated on the animals themselves. Dusting powders containing derris and pyrethrum have proved useful against lice, but DDT, BHC and malathion are more effective and longer lasting.

Sheep Ticks. Sheep ticks, *Ixodes ricinus* L. (Fig. 95), are troublesome pests in parts of Wales, North England and Scotland, where the hilly country provides extensive sheep and cattle ranges. They infest cattle and sheep from May onwards through the summer and autumn, and feed about the neck and ears and on the inner sides of the fore-legs and thighs where warmth, humidity and shelter favour them. Ticks are eight-legged animals, members of the class Arachnida, Order Acarina (p. 400). The head is extended into a blunt beak ; the central part of this is called the *hypostome* and has the mandibles ensheathed in the tip, and the two side parts are palps (Fig. 95, C). Ticks bury their beaks in the flesh of the host and suck

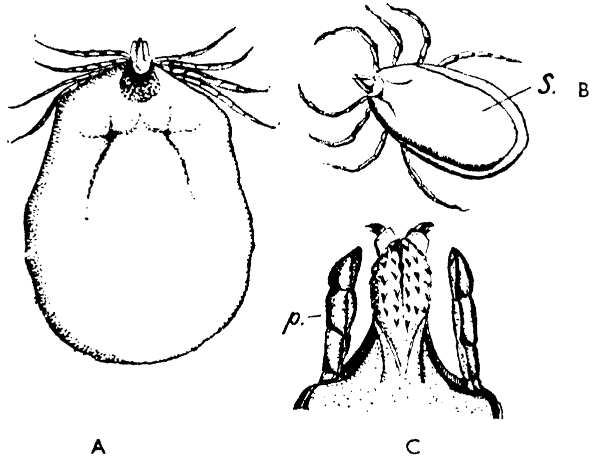

FIG. 95.—SHEEP TICK (*Ixodes ricinus*).

A, engorged female : × 6; B, male : × 6 ; C, front of head to show mouthparts : × 36 ; *s*, shield, *p*, palp.

blood. Before feeding, females are flat and somewhat triangular with a distinct black shield on the back; but after feeding the abdomen is distended with blood, and engorged adults may attain a length of a third of an inch (Fig. 95, A). When they finish feeding they fall to the ground where they lay eggs. The eggs hatch in autumn and the young ticks, which hibernate without feeding, have only three pairs of legs. After the first meal in spring they leave their hosts and moult and the fourth pair of legs is revealed. After each moult they seek a new host. Male ticks (Fig. 95, B) are small, black and completely covered by the dorsal shield. The feeding of ticks causes irritation and inflammation and they also transmit tick-borne fever in sheep and red-water fever in cattle.

Control Measures. Ticks require abundant moisture and a high degree of humidity in summer for their survival, and they are only numerous in districts where rank vegetation covers water-holding soil. This suggested that the improvement of hill pastures by draining, liming and the application of basic slag, and the removal of gorse and bracken cover by cutting and burning and by the introduction of store cattle would do much to create unfavourable conditions for ticks; and where such measures have been carried out trouble from ticks has abated. The introduction of the new sheep dips has reduced the tick problem to small proportions.

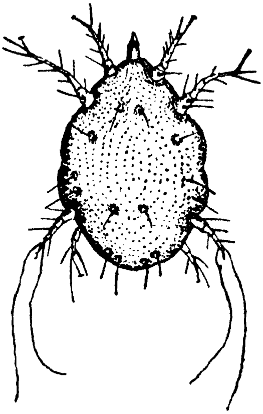

FIG. 96.—PSOROPTIC MITE OF SHEEP (*Psoroptes communis*): × 50.

Itch Mites, Scab Mites and Mange Mites. Itch mites, scab mites and mange mites, microscopic members of Acari, are the cause of scabies in man and parasitic mange in animals. They burrow into the skin and live and multiply under the scabs that cover the pustulating feeding sites. They are found on cattle, horses, swine and dogs, and constitute such a serious menace to sheep-rearing that their control on sheep is compulsory. The sheep scab mite, *Psoroptes communis* (var. *ovis*) Hering (Fig. 96), lives on the surface of the skin. Infested areas become raw and inflamed and the yellowish discharge dries and forms scabs over the sores. The mites under the scabs breed rapidly and the scabs increase in size, and infestation is indicated by the scratching and rubbing of the host. Attack usually begins in the thick wool on the back and withers, and is followed by loss of wool in large patches. A burrowing mite, *Sarcoptes scabei* (var. *ovis*) Meg., attacks the hair-covered parts of the head and produces small hard lumps that later become dry warty scabs. Foot mange of sheep is the result of infestation by *Chorioptes communis* (var. *ovis*) Verh., which is found chiefly on the lower parts of the legs and feet. Foot mange does not spread rapidly through the flock but it causes great discomfort and pain to the victims.

Control Measures. Animals infested by mites are frequently in pain and rub themselves against posts, palings and walls in their efforts to relieve the irritation. In this way scabs become detached and the mites spread to other individuals in the flock. Indeed, so contagious is parasitic mange that the sarcoptic and psoroptic forms in both sheep and horses must be notified to the Ministry of Agriculture. Until recently, arsenical and sulphur dips were widely used, but in 1948 the use of BHC was permitted in infected areas, as well as the employment of a single dipping technique. Since then, sheep scab has been eradicated from Great Britain, the last recorded case occurring in 1952.

Poultry Mites. There are four mites troublesome to poultry—Red mite *Dermanyssus gallinae* Deg., the Northern fowl mite *Liponyssus sylviarum* C. & L., the Depluming mite *Cnemidocoptes gallinae* Raill. and the Scaly Leg mite *Cnemidocoptes mutans* Robin. Other mites may also be found associated either with food or litter, and though they may sometimes give rise to alarm they are not dangerous and can usually be cleared up by hygienic methods.

The red mite is the most important of the four and attacks most species of poultry, especially hens and turkeys. It may live temporarily on domestic animals. Feeding takes place at night while the birds are on their perches and during the day the mites return to crevices in walls and perches. The engorged mite is red, but as digestion goes on it becomes grey in colour. Eggs are laid in crevices and in hot weather the life cycle may be completed in a week, hence build-up may be rapid. Infestations may be detected by the reddish black excremental marks most easily seen on the eggs. The fowls may suffer severely from blood loss if control measures are not quickly taken. These consist of the thorough cleansing and creosoting of the house followed by BHC or malathion or the more recent Sevin, which has been found to be very effective.

The northern fowl mite closely resembles the red mite but is permanently attached to its host ; hence it has to be dealt with by use on the birds of the insecticides just mentioned. The depluming mite which causes bare patches can be treated with 20 per cent benzoate emulsion, or 1 per cent BHC. Scaly leg mite, which burrows into the tissues, is not common and can be treated by carefully dipping the affected areas only into paraffin.

Chapter XV

PLANT BREEDING

Plant breeding applied to agricultural plants is a method of crop improvement, and as such it seeks to add to the efficiency and productivity of crop husbandry. There are many ways by which plant breeding can make positive contributions to crop husbandry, and the methods used vary according to the crop in question and the aims of the breeder, who must, if he is to contribute anything of value, study and appreciate the problems and requirements of the agriculturist. The great potentialities of plant breeding lie in the possibilities of offering the grower something new which either possesses advantages not found in the types already in cultivation, or which offers scope for cultivation under conditions which have hitherto been impossible or unprofitable for the particular crop. The greatest value of plant breeding is, therefore, its creative powers in the controlled production of desirable types, but it may also play an essential part in maintaining the standard of the varieties, strains and stocks already in cultivation. This latter function, however, important as it is for intensive and efficient crop husbandry, does not bring into play the essential feature of crop improvement which is the true role of plant breeding.

THE SCIENTIFIC BASIS OF BREEDING

Ever since plants were first taken into cultivation they have been subjected to unconscious or conscious improvement by growers, but it is only within recent historical times that plant breeding as a method of crop improvement has been developed intensively and organised on a rational basis. It was not until the discovery of sexuality in plants, and the understanding that came subsequently of the reproductive processes and life-cycle phenomena, that attention was focused on the causes of variability in plants and the possibilities of improving cultivated forms, particularly by creating new types. In the eighteenth century it was still a matter for debate as to whether all new varieties of cultivated plants arose from the variability of the soil in which they grew, or whether such things as natural hybridisation played a part; and it was not until artificial hybridisation was successfully accomplished and the progeny studied that the causes of variability in plants were more clearly appreciated and the possibilities of controlled breeding were visualised.

Towards the end of the eighteenth century the idea of plant characters being inherited first attracted serious attention from those interested in crop improvement; and early in the nineteenth century systematic hybridisation, with the study of the inheritance of individual characters, was a matter for investigation among a few interested workers. During this period, also, certain investigators became sufficiently knowledgeable and critical to realise that agricultural crops often consisted of a mixture of types, and that, by selection, new and improved varieties could be obtained. It also became apparent that the mixed nature of varieties as then cultivated was due partly to natural hybridisation, and that the only way to get rid of these " impurities " was to select from a single plant, or even a single grain. In this way the foundations of modern plant breeding were laid by the gradual accumulation of knowledge on reproduction, the causes of certain kinds of variability, the occurrence of natural hybridisation, the heritability of characters and the powers of artificial selection.

With this knowledge a great deal of valuable improvement of crop plants was effected, and agriculturists became very " variety conscious ". The means of improvement were showing themselves, but the methods still lacked certain essential knowledge to make them intelligible to the investigator and to show the full possibilities. This essential knowledge, which has done so much to enlighten the plant breeder and give him a better control of his methods and technique, as well as indicating the limitations and scope of plant breeding, has only come in the present century with the development of the sciences of genetics and cytology, and also with improved and more exact information on plant behaviour and physiology. The biological principles which have gradually been unfolded have done a great deal to replace in varying degrees the hit-or-miss methods of a plant breeding art by the more logical and controlled methods of scientific plant breeding which is using all the available proven knowledge and facts. That there are still serious limitations to the practical application of this knowledge to breeding will become apparent later in this account, but first it is necessary to consider the established principles and accepted theories on which modern methods of breeding are based. It will then be possible to discuss the application of these breeding methods to the improvement of the different kinds of crop plants and thereby to assess the value of the scientific knowledge available.

METHODS OF REPRODUCTION

Sexual reproduction is the normal method of reproduction in higher plants, but some species have developed asexual or vegetative methods in addition to, or in some rare cases more or less in place of, sexual reproduction. Asexual, or vegetative, reproduction may be used as an artificial means of propagating certain cultivated plants, such as apples, plums and cherries, which are naturally reproduced sexually, but in the case of the potato the natural vegetative means is also the plant breeder's and cultivator's method of propagation.

The higher plants differ from the higher animals in that the former are commonly hermaphrodite, or bisexual, while the latter are invariably unisexual. This means that in most plant species both male and female mature germ-cells, or reproductive cells (which are termed the *gametes* in sexual physiology and genetics), are produced on one plant. This consequently makes it possible for bisexual plants to be self-fertilised ; but self-fertilisation is by no means the invariable rule even in plants which bear bisexual flowers, and in hermaphrodite plants with unisexual flowers cross-fertilisation is common. In those plant species in which individual plants are unisexual, cross-fertilisation is a necessity for seed setting, and only the female plants bear seed and fruit. Thus reproduction in plants shows conditions varying from almost complete self-fertilisation to absolute cross-fertilisation, depending in the first place on the distribution of the sexes in the flowers and on the plants.

These fertilisation relationships are sometimes complicated by various kinds of *sterility* and *incompatibility*, which interfere with normal sexual relationships in certain plant species. Sterility may be *morphological*, due to the abortion or suppression of the stamens or ovaries ; or it may be due to a failure in the normal development of pollen, ovules, or early seed development, in which case it is described as *generational.* Sexual incompatibility, which may be partial or total, is not caused by any functional failure of the sexual parts or post-fertilisation development, but is due to partial or complete failure of pollen to reach the ovule and bring about fertilisation, in spite of there being sufficient pollen on the flower stigmas. It is possible to speak of self- and cross-fertility, and of self- and cross-incompatibility, according to whether one or more varieties, strains or species are involved.

It is obvious that all phenomena concerned with the method and mechanism of plant reproduction are the basis of methods of plant breeding, because it is only through the plant's reproductive capacity that propagation can be effected and breeding methods and technique can be devised. The breeder must know all the facts concerned, and in particular he must appreciate the distinction between asexually and sexually reproduced types, the amount of self- and cross-fertilisation, and the incidence of sterility and incompatibility.

HERITABLE AND NON-HERITABLE VARIATIONS

It is characteristic of all living organisms to show variability, and no two individuals are exactly alike. The visual and non-visual characters and characteristics of any individual at all stages of growth and development are the product of its hereditary constitution and of its environment, the latter modifying the former and causing *non-heritable variations*, *modifications* or *fluctuations*, which are not handed on to the progeny. It is well known that even identical twins are not identical in every respect, and the relative effects of " nature " and " nurture " have long been a problem of discussion and study and have considerable practical significance.

It was the recognition of the fact that selection within the progeny of pure breeding individuals cannot lead to any inherited improvement, because the variations are not heritable, that led to the concept of " pure lines ". This concept has had very important repercussions on plant breeding methods in relation to methods of selection and the basis for selection technique. It should be pointed out, however, that many so-called " pure lines " are in effect nothing more than "single plant selections" and are not necessarily "pure" in the genetic sense.

The recognition of the distinct nature of heritable and non-heritable variations was a great step forward for breeders of plants and animals. Early investigators were much hampered by the lack of any clear understanding of this distinction, although it was recognised that certain characters were transmitted from parent to offspring. On the other hand, although " like tends to beget like " through sexual reproduction, and in asexual reproduction the vegetatively produced individuals are all possessed of the same hereditary characters, variability is one of the essential characteristics of living organisms. This is really only another way of saying that it is not characters as such which are inherited, but merely the ability and tendency to develop and manifest in a particular way under different environments ; and the circumstances of the environment may not only modify the expression of individual characters, but may actually determine whether or not certain characters ever express themselves at all.

Heredity, through sexual reproduction, is a potent cause of variation by bringing about the recombination of parental characters and the production of new types in the offspring. Hereditary variation brought about by hybridisation is one means by which evolution has taken place through natural selection, and it is also the hope of the breeder who is striving to create new and improved forms. The early hybridists were bewildered by the prolific production of new types by hybridisation, and most of them failed to profit by this method of breeding because they had no knowledge of the mechanism of inheritance and consequently did not understand how to handle hybrid progenies.

MENDELISM

The first successful scientific attempt to explain the mechanism of inheritance resulted from Mendel's experiments on hybridisation, as a result of which he formulated certain " laws ". Mendelism is often loosely thought of as synonymous with heredity and the modern science of genetics, but this is not so, although Mendel was the first investigator to analyse satisfactorily the mode of inheritance of certain characters. As a result of his experiments Mendel was able to establish, not only certain principles governing a particular type of inheritance (Mendelian inheritance), but also to indicate a mathematical precision in inheritance and a method of handling progenies which has provided the basis of breeding technique.

Mendel worked with the garden pea, which is a self-pollinating plant, and he studied the inheritance of green and yellow seed leaves (cotyledons), grey and brown seed coat, round and wrinkled seeds, green and yellow pod, purple and white flowers, distribution of the flowers, and tall and dwarf plants. The significant features of Mendel's work were that he studied the inheritance of each character separately ; that he observed critically the characters in the first hybrid generation ; that he counted the proportions of the plants with the different characters in the second generation ; and that he followed the hereditary behaviour into the third generation. During this work he appreciated the necessity for keeping the progeny of individual plants separate ; in this way he was able to study the breeding behaviour of single plants with regard to the particular characters, and he used this information to interpret the inheritance of the individual characters in the whole progeny. Not content with this evidence, Mendel tested and verified his hypothesis concerning the mechanism of the inheritance of these characters by a full analysis of the second-generation progenies, and thereby introduced the important technique of progeny testing which is now regarded as essential for all work on heredity and breeding.

Mendel's contribution to the study of inheritance is of outstanding importance because he established three important concepts and a fundamental technique. In addition, he demonstrated that the inheritance of certain characters, as expressed in the second-generation progeny, is mathematically so precise that it can be represented in absolute ratios according to the numerical representation of the characters in the individuals of the progeny.

The three Mendelian concepts are first, that the characters he studied behaved as separate units in inheritance. Second, that in the second generation the characters are independently assorted and that they separate or " segregate " at random among the individuals of the progeny. Third, that a particular character expression can dominate an alternative character expression so that, although both expressions may be carried by one individual, only the " dominant " character expression can show itself.

In addition to observing the way in which the characters he studied were inherited, Mendel provided the explanation in terms of the hereditary constitution of the male and female gametes, and in this way for the first time associated hereditary behaviour with the processes involved in sexual reproduction.

Mendel had observed that constant forms appear in the progeny of hybrids, and that this happened with regard to all combinations of the associated characters. He confirmed that " constant progeny can only be formed when the egg cells and fertilising pollen are of like character, so that both are provided with the material for creating quite similar individuals " and he amplified this by stating, " we must therefore regard it as certain that exactly similar factors must be at work also in the production of the constant forms in the hybrid plants. Since the various constant forms are produced in one plant, or even in one flower of a plant, the conclusion appears logical that in the ovaries of the hybrids there are formed as many sorts of egg cells, and in the others as many sorts of pollen cells, as there are possible constant combination forms, and that these egg and pollen cells agree in their internal composition with those of the separate forms. In point of fact, it is possible to demonstrate theoretically that this hypothesis would fully suffice to account for the development of the hybrids in the separate generations, if we might at the same time assume that the various kinds of egg and pollen cells were formed in the hybrids on the average in equal numbers."

Mendel confirmed these assumptions also by carefully planned experiments and thus completed the evidence on which his principles are based, and from which the science of genetics has been developed.

GENETICS AND CYTOLOGY

Although Mendel's account of his work was published in 1866 it attracted little attention until 1900, when three investigators (de Vries, Correns and Tschermak) gave independent accounts of their own experiments in which they were able to confirm Mendel's principles in plants. Two years later, Bateson and Cuernot showed that the inheritance of certain characters in animals could also be explained on Mendelian principles. With the accurate accounts which had just previously been given on the mechanism of fertilisation and the recognition of the importance of chromosomal activity in cell division and fertilisation, the essential basic facts for the development of genetics and cytology were realised and appreciated.

Such fundamental facts as the constancy of chromosome numbers, and the splitting of chromosomes in cell division in the body cells, were known before the re-discovery of Mendel's paper, and the idea of the cell nucleus as being the basis of heredity, with the later but still pre-1900 discovery of the reduction of the number of chromosomes in the reproductive cells, cleared the way for the rapid developments of the twentieth century. This study of the cell and its contents, particularly the nucleus, with the cellular interpretation of the phenomenon of sexual reproduction, quickly suggested a working hypothesis to explain what was then known of inheritance ; and in 1902 the close association of chromosomal behaviour and Mendelian segregation was first recognised.

Chromosomes and Heredity. The parallel development of knowledge in cytology and heredity rapidly led to the formulation of the chromosomal theory of inheritance, which received further confirmation from the demonstration that there were definite sex chromosomes in higher plants and animals and that sex is an inherited character which is determined by chromosomal behaviour. It is now generally accepted that the chromosomes are the bearers of the factors which determine most hereditary tendencies and manifestations. This explanation gives a constructive basis for studying the principles of inheritance, although there are undoubtedly exceptions, particularly demonstrated in plants, of *extra-chromosomal* inheritance and maternal effects which are due to influences outside the chromosomal mechanism.

Genes. The chromosomal theory of inheritance is based on the concept of the chromosomes bearing, in a linear arrangement, *genes* or factors which determine the development of the characters of the particular organism, and also which control the manifestation of each character within the limits set by the particular environmental conditions. Each chromosome may carry many genes, and a particular character expression may be decided by one or more genes, so that the ultimate characteristics of any organism are decided not only by the presence of particular genes as they affect a particular character expression, but also by the interaction of these genes and the modifying effects of the environment. The simplest forms of inheritance are found when a character difference depends on a single gene difference, as Mendel found in the pea characters with which he worked. But it is commonly the case that more than one gene is involved, and when this is the case the mode of inheritance may become difficult to interpret, particularly when the environment has a strong modifying effect on the expression of the character.

Meiosis and Mitosis. If the chromosomes are the principal determiners of the hereditary constitution and behaviour of living organisms, it is obvious that their stability, behaviour and structure are of fundamental importance. Every organism is characterised by a particular chromosomal complement, by which is meant a definite chromosome number composed of individual chromosomes with a characteristic and specific structure. Of the total number of chromosomes present in the body cells of any individual, half are contributed by each parent when the two reproductive cells or *gametes* come together to form the *zygote* on fertilisation. It is clear that if the chromosome number is to remain the same from generation to generation, and not to double with each successive fertilisation, there must be a special mechanism to provide for this. The means by which this is brought about is that in the formation of the reproductive cells the number of chromosomes is halved by a *reduction division* during the nuclear divisions (Meiosis) which take place in the formation of gametes in the reproductive organs. All other nuclear divisions which take place when the zygote develops after fertilisation are characterised by a longitudinal splitting of each chromosome, so that each body cell has represented in it the hereditary material of each and every chromosome. This type of nuclear division is termed Mitosis, and by this means every body cell of the individual carries an identical chromosomal complement. (See Plates XXXI, XXXII.)

During mitotic division the nucleus of the cell passes through a number of distinct phases which take place in an orderly and invariable sequence in normal divisions. The characteristic appearance of the " resting " nucleus shows a dense granular structure, spherical in shape, more or less in the centre of the cell (Plate XXXI, Fig. 1). During the first phase (*prophase*) this granular structure resolves itself into a number of double threads ; these are the chromosomes, which have divided longitudinally at an earlier stage (Figs. 2 and 3). Subsequent continued coiling results in contraction and thickening of the chromosomal thread. When the chromosomes have reached their maximum state of contraction, the membrane round the nucleus disappears, the double threads become arranged on a flat plate across the cell (*metaphase*), and the so-called spindle is formed, the equator of which is the plate (Fig. 4). The " daughter " chromosomes formed by the splitting of each individual chromosome now separate, and one of each twin moves to the opposite end of the cell where the poles of the spindle are situated (Fig. 5). This is termed the *anaphase*, and the net result is that two identical chromosome groups are formed which are also exact replicas of the original. The chromosomes then uncoil and the original granular nature of the nucleus is restored (*telophase*) in the two daughter nuclei between which a new cell wall is formed (Fig. 6).

The characteristic structure of chromosomes in individual species of plants can best be seen by examining nuclei from the polar view, when the number and special features of the chromosomes can be seen as the latter lie on the spindle plate before separation to the poles (Figs. 7, 8, 9). At this stage, also, the double nature of the chromosomes formed by splitting can commonly be distinguished very clearly, while the distinct structure of individual chromosomes within the complement of the plant is sometimes very striking (Fig. 7).

Linkage and Crossing Over. It is by means of reduction division that segregation of genes, and consequently of the hereditary characters that they control, takes place. The random assortment of the half, or *haploid*, number of maternal and paternal chromosomes which follows, means that reproductive cells of many different genetic constitutions are formed according to the particular chromosomes that they carry. But there cannot be a complete random assortment of all the hereditary characters at this time because the genes which are carried on any one chromosome tend to be *linked*, and the closer together they are on the chromosome, the closer will this linkage be.

However, in addition to the random assortment of individual chromosomes at meiosis, there is an additional source of variability in the kinds of reproductive cells formed by reason of the peculiar behaviour of the chromosomes. During meiosis, maternal and paternal chromosomes of similar structure (*homologous pairs*) pair and become physically connected, and during the close pairing transverse breaks may occur in the chromosomes, and when they join up different pieces may come together to form a new chromosome. By this means, *crossing over* of chromosomal pieces can take place, and the pairs of chromosomes come out of the pairing with one or more parts of their lengths interchanged. In this way there is a recombination of parts of similar chromosomes, and structural changes in the chromosomes result (see Plate XXXII).

Meiosis shows a number of distinct phases which are characteristic of this form of nuclear division and which normally take place

PL. XXXI. STAGES IN THE DIVISION OF A CELL NUCLEUS : MITOSIS

1. Cell with nucleus in resting stage.
2. Chromosomal threads showing double structure (prophase).
3. Later stage showing contraction and thickening of chromosomal threads (prophase). The individual chromosomes are still too long for separate identification.
4. Final contraction of chromosomes and arrangement on equatorial plate : side view (metaphase).
5. Daughter chromosomes moving to opposite poles of spindle : side view (anaphase).
6. Two daughter cells formed from the division, with the dividing cell wall evident.
7. The ten chromosomes (two sets of five) of a species of *Trillium*. These show the structural differences between different homologous pairs of the complement.
8. The forty-eight chromosomes of the domestic plum.
9. The twenty-four chromosomes of the Sitka spruce.

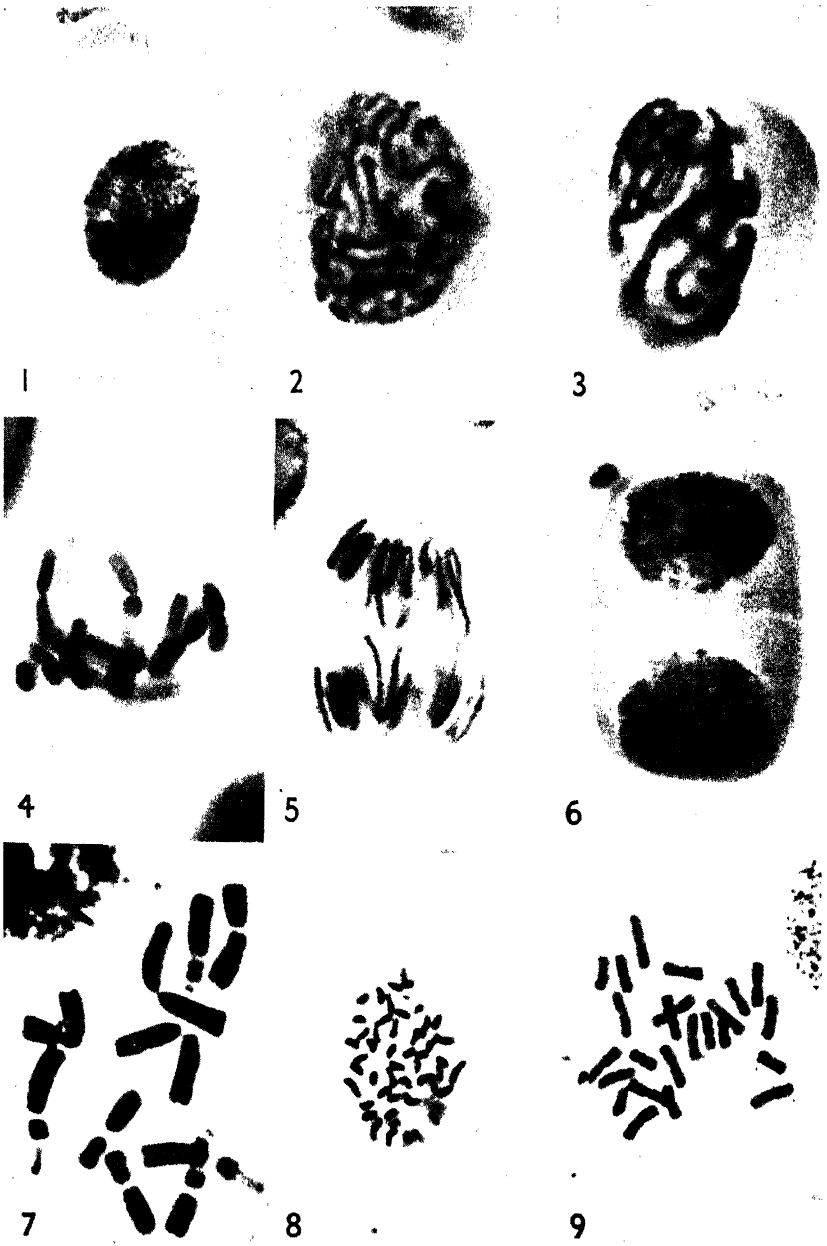

PLATE XXXI. STAGES IN THE DIVISION OF A CELL NUCLEUS—MITOSIS
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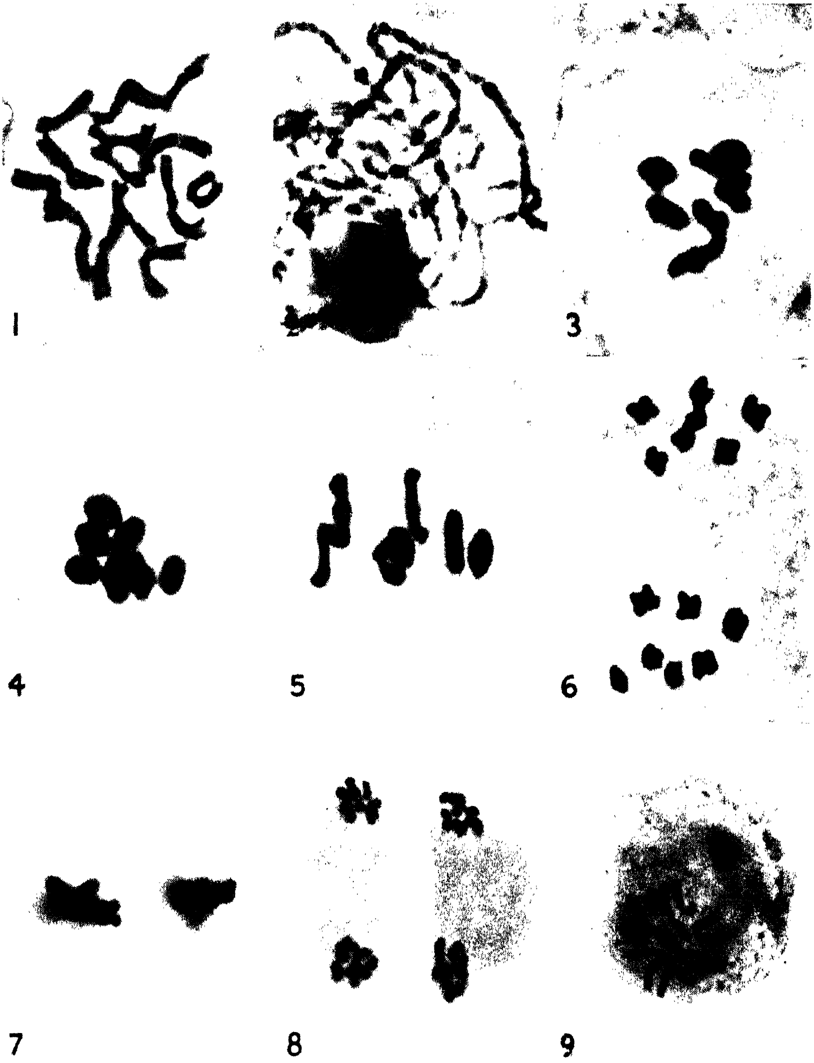

PLATE XXXII. STAGES IN THE DIVISION OF A CELL NUCLEUS—MEIOSIS
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in an orderly and invariable sequence as is the case in mitosis. Nuclear division begins before the chromosomes have split in the nuclei of cells which are going to form gametes, the homologous pairs come together and pair side by side (Plate XXXII, Fig. 2). At this stage the chromosomes are long thin strands which are differentiated along their lengths, and they then divide to give four strands, thus providing opportunity for exchanges of partner within the paired chromosomes by means of breakage and reunion of strands as mentioned in the previous paragraph. The chromosomes then contract and thicken, the pairs still lying together, after which they become arranged on the spindle plate (Figs. 3 and 4) ; then one chromosome (still showing its double structure through splitting) moves to opposite ends of the cell (Fig. 5). This results in half the original chromosome numbers aggregating at each end (Fig. 6), and then by a subsequent nuclear division, during which the chromosomes split and separate, each daughter nucleus forms two nuclei (Fig. 7). The two divisions thus result in four daughter nuclei, each with half the original chromosome number (Fig. 8), and each representing a potential gamete as in the case of the pollen grain illustrated in Fig. 9. It may be seen, therefore, that meiosis consists of two divisions of the nucleus with only one division of the chromosomes.

Homozygosity and Heterozygosity. The mode of inheritance of characters is studied by analysing the progeny in the first, second,

PL. XXXII. STAGES IN THE DIVISION OF A CELL NUCLEUS: MEIOSIS IN *LOLIUM* (RYE GRASS)

(Only Figs. 2–8 show stages of Meiosis. Figs. 1 and 9 illustrate mitosis, Fig. 1 to show diploid chromosome number for comparison, and Fig. 9 to show later development of pollen grain.)

1. The fourteen chromosomes (two sets of seven) from vegetative (somatic) tissue to show the diploid chromosome number.
2. The pairing of homologous chromosomes, which at this stage are long, thin strands (first division prophase).
3. Paired chromosomes (seven pairs) after contraction. The pairs are called bivalents.
4. The seven bivalents on the equatorial plate: end or polar view (first division metaphase).
5. The seven bivalents on the equatorial plate: side view (first division metaphase as in Fig. 4 but slightly flattened).
6. The seven daughter bivalents formed at each end of the cell as the result of reduction division (first division late anaphase).
7. The daughter bivalents arranged on the two plates preparatory to the second (mitotic) division (metaphase, side view).
8. The resulting four cells (the tetrad) each with half the somatic chromosome number. Each chromosome shows a middle constriction (second division telophase).
9. One pollen grain with the half chromosome number (seven). Each pollen grain will usually have a different combination of genes due to exchanges of partner within the bivalent and also due to the random orientation of the bivalents during division. Mitosis is taking place in this pollen grain, with the production of the generative and tube nuclei.

third and possibly subsequent generations after hybridisation. Genetics is therefore essentially progeny testing and analysis based on quantitative data and capable of mathematical expression in terms of numbers and ratios. In order to study critically the mode of inheritance of any character it is necessary to choose two parental types that are true breeding for the contrasting character expressions, as Mendel did with his purple- and white-flowered peas. Such pure breeding individuals are said to be *homozygous* for the particular character, while individuals which are not true breeding are *heterozygous*. For example, the first generation hybrid is heterozygous for all the characters in which the two parents differ, and such hybrids will not breed true for those characters. But in the second generation and subsequently, a certain proportion of true breeding forms will be formed, the number depending on the number of genes which control the expression of the character.

Genotype and Phenotype. The genetic constitution, or *genotype*, of any individual cannot be determined by its appearance, or *phenotype*, because it may not be true breeding for one or more of the characters expressed in its body or by its behaviour, and it may be carrying *recessive* genes which cannot express themselves because of the presence of *dominant* genes. It may also happen that there may be an *inhibiting* gene, or that the expression of a character depends on *complementary* genes or complex *gene interaction* and the presence of *modifiers*. All these possibilities make it necessary to concentrate on genotypic constitution as shown by progeny testing and breeding behaviour when studying inheritance, and they are absolutely essential to bear in mind when applying genetic knowledge to practical breeding.

Polyploidy. Further complications can arise in genetic behaviour through more than two sets of chromosomes being present in any individual. This condition is known as *polyploidy*, and organisms having more than the normal *diploid* chromosomal complement are called *polyploids*. Polyploidy is rare among animals, being absent in higher animals, and occurring regularly only in certain lower animals that are hermaphroditic or which reproduce asexually (partheno-genetically). Polyploid forms are, however, common among higher plants, certain families and genera tending to be prolific in their production, and the condition is particularly characteristic of certain groups of cultivated plants such as the Gramineæ where, for example, in addition to the diploid species there are species with four sets of chromosomes (*tetraploids*) and species with six sets of chromosomes (*hexaploids*). There are other genera, however, which show a wider range of polyploidy than does wheat, and very high multiples occur in such crops as sugar cane. Polyploidy has undoubtedly played a most important part in the evolution of some cultivated plants, and it has a very significant effect on plant breeding. Not only does it influence hereditary behaviour, but it also introduces complications in relation to the crossability of forms possessing different chromosome numbers, while the artificial production of polyploids is a means of overcoming hybrid sterility and a method of creating new forms.

THE APPLICATION OF GENETICS AND CYTOLOGY

In the early days of Mendelian and genetic experimentation it was thought that the problems of plant, and to a lesser extent of animal, breeding methods were solved, and it only remained for breeding material to be subjected to a complete genetical investigation for the way to be made clear for the creation of new desired types at will. But breeding has never become merely a matter of applied genetics, although with cytology, genetical science has supplied an invaluable means for obtaining a greater measure of control over breeding material, while the genetical and cytological approach to some breeding problems has yielded astonishingly profitable results in practical plant breeding. Methods of breeding are to a large extent based on the knowledge which has accumulated in genetical research, while cytological phenomena have not only provided the explanation of certain genetic principles, but they have also suggested the means for the development of new techniques in breeding methods. But it is well to remember that the methods of the geneticist and the cytologist on the one hand, and of the practical breeder on the other, are quite distinct ; for whereas in the former case the object is interpretation and analysis, in the latter the objective is selective and creative with the production of new types of practical worth.

Naturally a knowledge of the fundamental concepts and the most up-to-date developments in genetics and cytology is a virtual necessity for the breeder, although the extent to which both the knowledge and the developments can be applied to the actual breeding methods and technique must vary considerably with the plant or animal in question, the problems involved, and the objectives. In some agricultural and horticultural plants the whole basis of the breeding rests on exact genetical and cytological knowledge, and the limitations and technical complications of the breeding technique are firmly grounded on a genetical and cytological approach. At the other extreme the breeder has little to guide him other than his general knowledge and experience of the crop, combined with his skill in the art of plant breeding.

BOTANICAL RELATIONSHIPS

The breeding of any crop requires more than a thorough knowledge of the agricultural varieties already in existence and cultivation. The breeder needs to be familiar with all the botanical variations available in the species and genus with which he is concerned, as well as understanding the relationships with allied groups of forms in different species and genera. It is only through such knowledge that the possibility or limitations of transferring valuable characters from one group of plants to another can be decided, and the possibilities of improvement by " wide-crossing " or " distant hybridisation " be assessed. If such knowledge is not available, and such possibilities are not taken into consideration, the breeder is immediately imposing limitations on his methods and the scope of the improvements which he can visualise.

PHYSIOLOGICAL AND DEVELOPMENTAL PHENOMENA

The study of the hereditary behaviour of plant characters has often tended to obscure a proper knowledge and understanding of the characters themselves. Genetic knowledge is quite inadequate without a fundamental knowledge of the characters, particularly when these characters are of a complex physiological nature affecting growth, development, yield and the various important attributes included in " quality ". Great advances have been made in the knowledge of some of these plant characters and attributes during recent years, and their inter-relationship or incompatibility are matters of prime importance to the breeder. It is seldom that the plant breeder is not concerned with physiological problems sooner or later, and in particular is he concerned with the plant and its environment and the fundamental processes governing growth at all stages. The morphological manifestations of physiological activity, such as ear size and weight, and grain characters in cereals, or root conformation, weight and sugar content in sugar beet, are equally important as subjects of study and investigation, and in all cases must there be as complete an understanding as possible of all the plant, characters.

GROWER AND CONSUMER REQUIREMENTS

Scientific knowledge combined with skill as a breeder are essential for success in plant breeding, but by themselves they are insufficient. The improvement of agricultural plants requires a close and intimate association with agriculture, so that the problems of crop production can be readily appreciated. To be most effective the breeder must set out to provide the grower with new varieties or strains of crop plants which contribute to the efficiency of production either by the improvement of field characters, or by meeting the requirements of the consumer more satisfactorily by improvement of the quality of the product. It is by either or both of these means that plant breeding can bring about progressive improvements in crop husbandry by supplying the grower with better material for cultivation.

METHODS OF PLANT BREEDING

The methods employed in the breeding of improved varieties and strains of agricultural plants are determined in the first place by the method or methods of reproduction, the fertility and incompatibility relationships, and the life cycle phenomena of the plant or plants with which the breeder is working. In addition to these biological considerations, the breeder will have to plan his methods in relation to the kind of improvement he has in mind and the material with which he is going to work, or which is available to serve as a basis for his investigations.

The following types of sexually reproduced plants as affecting the methods of breeding can be distinguished :—

1. Normally self-pollinated, and showing no intra-specific self-sterility complications, e.g. wheat, barley, oats.

2. Normally cross-pollinated, and showing no self-sterility complications, e.g. maize.
3. Normally cross-pollinated, but showing varying degrees of self-sterility complications, e.g. sugar beet, grasses and clovers.
4. Mostly self-pollinated, but with a high degree of cross-pollination, e.g. beans.
5. Invariably cross-pollinated due to unisexual individuals, e.g. hops.

There are, in addition, those species which are normally reproduced vegetatively and which show complete or partial sexual sterility according to the variety, as in the domestic potato ; while in rare cases, as for example in smooth-stalked meadow grass, seed is produced without normal sexual fertilisation (i.e. apomictically).

These reproductive phenomena determine not only the planning of breeding programmes, the material that can be used and the methods to be adopted, but also the finer points of handling the breeding material and the technical procedure during the carrying out of the programme once it has been planned.

But, in spite of these complications (which after all are primarily concerned with deciding and modifying the technique of breeding), there are only two important fundamental methods of breeding crop plants, and these two methods are applicable to all the common crops. Although it is convenient to consider the two methods separately, it is seldom that either is used exclusively for any particular crop ; one method may serve as the basis of improvement, while at the same time incorporating the other. We may, therefore, consider breeding methods and their application to common farm crops under the major headings of Selection and Hybridisation. In the course of the following discussion it will become apparent that these methods are not mutually exclusive, but that most breeding involves the use of both.

SELECTION

It may be said that some form of selection is the basis of all plant breeding ; but, for the sake of clarity, selection may here be considered without the complications of hybridisation or other methods of creating new types and greater variability on which to practise selection. For the moment, therefore, we may consider selection as a means of improvement by the exploitation of already existing variability in mixed populations. The various kinds of selection applicable to different crops are as follows :—

Single Plant Selection. This may be used in mixed populations of self-pollinating crops, and is the first and most obvious means for seeking improvement when starting the breeding of such crops. Before intensive breeding of such crops as the cereals was organised extensively in this country, a large number of improved varieties was produced by selecting the outstanding plants within commercial varieties, and multiplying new stocks by propagating from single plants. By this means improved stocks of wheat, oats and barley were put on the market ; in more recent times Victory oats, Squarehead's Master 13/4 wheat, the various kinds of Archer barley and the early selection of Spratt-Archer barley named Earl were developed by this type of selection.

The scope for this type of improvement naturally depends on the amount of variability present in the stocks that are used for selection. In some cases, where stocks are obviously composed of easily discernible mixtures, improvement may result from " purifying " these stocks, or by picking out particularly outstanding plants similar to the bulk of the stock. Where stocks are apparently " pure " it may be necessary to select apparently similar types, and test the progenies of the single plants with great care to see whether any improvement can be obtained in such characters as yield, quality or perhaps resistance to lodging. The ease with which improvement can be obtained, and the type of improvement possible, will therefore depend on the variation in the stock before selection starts ; obviously the chances of improvement become less as the stock is progressively purified. The stocks of cereals in this country at the moment offer little scope for any great improvement in this way because all the standard varieties have been subjected to intensive selection.

In the past, great improvements in certain cereals have been effected by the chance selection of isolated plants of unknown origin, as in the case of Potato oat, Chevalier and Goldthorpe barley, and possibly also Squarehead's Master wheat, although there is some doubt of the origin of this wheat variety. The possibility of bringing about radical improvement by such chance selections is naturally becoming less and less as the commercial stocks and the standard of the cultivated varieties improve, but the history of our cereal varieties shows the important part played by this means.

Mass Selection. This may be practised in both self-pollinating and cross-pollinating crops. In the self-pollinating cereals (wheat, barley and oats), the best plants typical of the variety may be selected and bulked together to form a new nucleus stock for multiplication. Such selection rarely leads to any radical improvement, but the method may be used to maintain the stock at a satisfactory level.

In cross-pollinated crops, such as rye and sugar beet, a modified form of mass selection is a standard method for improvement. The individual plants are normally grown on and the value of each selection is judged by the behaviour of the progeny, i.e. " progeny testing ". The lines, or progenies, thus established may be inbred for a varying number of generations to test their performance, and this is normally accompanied by a loss in vigour varying in amount with different crops and within the lines of any one variety of a crop. When the lines have eventually been chosen, they are all grown on in one isolation plot and allowed to interpollinate to produce the new stock of selected seed.

Group Selection. In herbage plants the basis of strain (i.e. variety) building may be the selection of small groups representing a desired type, e.g. hay or grazing type, that it is desired to establish. Single plants showing the desired characters are grown together and their type is tested and judged by multiplying the individual plants vegetatively to establish *clones* which offer a better opportunity for selection of the right type. The selections may be inbred for a few generations to obtain a better idea of their genetic constitutions before allowing interpollination between the selections ; or alternatively the most satisfactory clones may be allowed to interpollinate to produce the stock seed of the new strain for trial.

In both mass and group selection breeding, the value of the individual lines for serving as the basis of new stocks may be tested by hybridising the lines in pairs. In this way the breeding value of the lines can be judged in various combinations, and the expression of any " hybrid vigour " can be observed. This is a most important procedure in the breeding of all cross-pollinated crops, and it has been found that not only does the compatibility between different lines vary, but also the hybrid vigour expression. On this basis the best combinations of individual lines for cross-pollination can be utilised for establishing a new strain.

It is obvious that the basis of selection, and the technique of handling the material, will depend on the life cycle of the crop plant under investigation and the nature of the character or characters that are being studied. In the case of self-pollinated annuals such as wheat, barley and oats, selection on all the important characters may proceed during each growing season in an uninterrupted sequence. But where the crop is a biennial, as in sugar beet, mangels and certain Brassicas, selection for the important field characters is made in one year, and then the selections have to be grown for seed the following year before the material can be tested again. Further complications may be experienced in such biennials where the actual seeding habit and seed characters themselves are important for selection study in addition to the actual crop product itself. This is the case in sugar beet, where not only must selection be based on the root, but also on the type of seeding plant and the morphology and physiology of the " clusters " (i.e. the commercial seed).

In perennial herbage plants it is necessary to continue selection of the same material over a number of years before the true value of the material can be judged, particularly when the breeder's judgment and tests have to be based on sustained productivity over a number of years, and on persistence under different systems of management. In these circumstances it may take years before even initial selection of basic material for breeding can be satisfactorily achieved, and progress is necessarily slow. There is, however, the advantage in herbage plant breeding of there being a vast reserve of naturally occurring variation on which the breeder can practise selection without the necessity of creating new variability by controlled hybridisation.

It is seldom that any breeding material or any form of selection for direct commercial improvement allows the breeder to concentrate on one character only. Such a luxury can only be experienced when the material is stable for all the important field and commercial characters which are likely to affect the value of the selection product, other than the one on which the breeder is selecting. In most cases, however, attention has to be paid to all the economic characters during the period of selection to prevent selection of one character being made at the expense of losing the best expression of other characters.

HYBRIDISATION

The use of hybridisation as a method of crop improvement is commonly directed to three main aims—the transference of one or more desirable characters ; the increase of the range of variability by introducing various character recombinations ; and the direct and controlled exploitation of hybrid vigour. In the first two cases the main objective sought is increased variability by combining characters of more than one individual in a single plant ; while in the third case the aim is either to restore vigour which has been lost by inbreeding, or to improve the level of productivity by concentrating the desired genetic factors.

As a method of crop improvement, hybridisation is effective only in so far as it brings about the kind of character recombination or expression of greater productivity and vigour that is desired ; and it must be accompanied by efficient selection. Haphazard and random hybridisation as a mere speculation is seldom effective, and all breeding based on hybridisation should be made with a clear objective. To plan improvement in this way, therefore, it is first necessary to select the parental material that is most likely to give the type of improvement required, and before this can be done the full range of potential parents must be known intimately. With reliable knowledge of this kind, and with a definite object in view, selection in the hybrid generations which follow can be most efficiently carried out. The success of any hybridisation experiment is determined by the thoroughness and efficiency of this subsequent selection, provided always that the choice of the parents was a happy one, and that the objective was practicable.

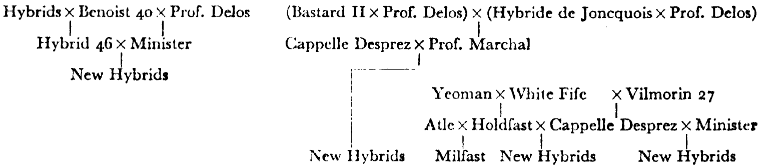
According to the relationship between the parents chosen, hybridisation may be planned under the following categories :

Intra-Varietal (and Intra-Strain) Hybridisation. It has been claimed that hybridising selected individuals within one variety of a self-pollinated crop can bring about improvement, particularly by enhancing yield. It seems clear that such improvement is only possible if the so-called variety is in reality a mixture of different genotypes which on hybridisation produces new combinations showing better combinations of economic characters. No effective improvement by this means has been recorded in this country where the standard of purity of reliable stocks of commercial varieties is high.

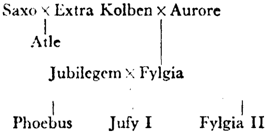
In cross-pollinated crops, however, such as sugar beet, grasses and clovers, where the varieties are genetically heterogeneous, controlled hybridisation within the varieties is used to maintain and improve individual varieties. The possibilities of improvement by this method can be readily appreciated by what has already been said of the genetic variability of these cross-pollinated populations ; the scope of the improvement possible depending on this genetic variability, the effectiveness of the selection of lines for hybridisation, and the extent to which compatible combinations are obtained which show increased vigour after selection of the lines by inbreeding. Intra-strain hybridisation is a standard and recognised method of breeding certain types of cross-pollinated crops, and the so-called " hybrid maize" developed in the U.S.A. is an outstanding example of this type of improvement.

Inter-Varietal Hybridisation. The basis of the improvement of most self-pollinating crops is at present inter-varietal hybridisation, and by far the greatest number of new varieties at present in cultivation has been produced in this way. In most cases, also, successive improvements have been built up by an orderly system of planned breeding whereby one improvement has been used as the means of the next step forward by an intensive scheme of inbreeding within related forms. The most important progress has also resulted where breeders engaged in particular areas and engaged in special lines of improvement, have concentrated on the use of specially valuable parental varieties which have proved their worth in breeding. Both of these important characteristics of inter-varietal hybridisation—orderly synthesis and the use of certain valuable parents—can be illustrated by reference to the following pedigrees :—

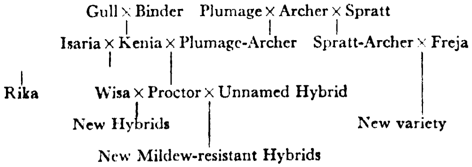
WINTER WHEAT


Hybrids × Benoist 40 × Prof. Delos
Hybrid 46 × Minister
New Hybrids
(Bastard II × Prof. Delos) × (Hybride de Joncquois × Prof. Delos)
Cappelle Desprez × Prof. Marchal
Yeoman × White Fife × Vilmorin 27
Atle × Holdfast × Cappelle Desprez × Minister
New Hybrids
Milfast
New Hybrids
New Hybrids

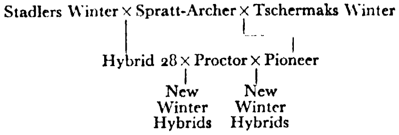
SPRING WHEAT



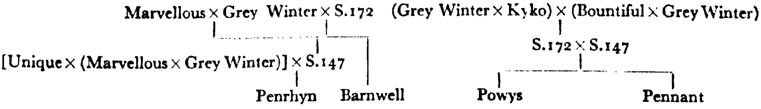
SPRING BARLEY


Gull × Binder
Plumage × Archer × Spratt
Isaria × Kenia × Plumage-Archer
Spratt-Archer × Freja
Rika
Wisa × Proctor × Unnamed Hybrid
New Hybrids
New variety
New Mildew-resistant Hybrids

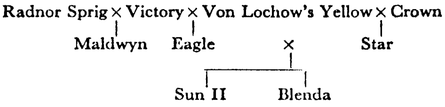
WINTER BARLEY


Stadlers Winter × Spratt-Archer × Tschermaks Winter
Hybrid 28 × Proctor × Pioneer
New Winter Hybrids
New Winter Hybrids

WINTER OATS


Marvellous × Grey Winter × S.172
(Grey Winter × Kyko) × (Bountiful × Grey Winter)
S.172 × S.147
[Unique × (Marvellous × Grey Winter)] × S.147
Penrhyn
Barnwell
Powys
Pennant

SPRING OATS



These pedigrees show how some of the important varieties cultivated in Britain have been derived. Foreign bred varieties have been introduced into this country on a large scale, and some have achieved considerable success in agriculture. These varieties, and other foreign varieties possessing special characters of particular value, have been used in breeding programmes in this country, while current breeding work is tending to exploit a wider range of varieties. The new hybrids and new varieties to which reference is made in the pedigree charts for winter wheat, spring barley and winter barley, are actual derivatives of a breeding programme, and have not been included as theoretical developments or possibilities.

Such methods must be accompanied by intensive selection after hybridisation. It is usual to make single plant selections in the second generation and to assess the progenies in the third generation purely by observation, at which time it is normal to select single plants again. Observation and selection of this type, accompanied by testing for disease resistance, may continue for several years—up to the sixth or seventh hybrid generation—until the desired type is " fixed " for all the observable characters. This stage is then followed by small-scale yield trials, testing for quality and perhaps also for field characters when judged in bulk, for three years, by which time the value of the selections should be known with some precision if all the tests have been accurately conducted. It may be noted that the early generations of selection are judged very largely on the eye judgment of the breeder, and there is little else of a practicable nature to take the place of this judgment except in certain cases where controlled tests as for disease resistance can be used. Although the mode of inheritance of some or all of the characters with which the breeder is working may be known, this will help very little in the actual selection of the desired types in the field. Moreover, it is more commonly the case that the complex agricultural and economic characters with which the breeder works are difficult to analyse genetically and are much affected in their expression by the growing conditions.

An alternative to the above method of successive single-plant selections in the early generations is to bulk the produce and take a sample for sowing in each of the first four or five generations, and only start to make single-plant selections subsequently. This method allows the plants to become increasingly homozygous before selection, and also has certain advantages in allowing natural selection to act on the mixed population before " artificial " selection starts. There is, however, the great disadvantage of not having the material under close selection control in the early generations, and the method is not generally popular.

With vegetatively propagated plants like the potato there is no need to continue selection until the hybrids are pure breeding or approaching the homozygous condition. Indeed, homozygosity may be considered undesirable because the plants when heterozygous can be expected to show some hybrid vigour. Accordingly the first generation hybrids are each bulked up and the so-called " seedlings " are judged and selected in relation to the particular characters for which the worker is breeding, and there is in consequence selection in one generation only. This means, of course, that any new variety which may be put on the market in this way is a clone derived from a heterozygous first generation hybrid which remains stable only because it is vegetatively propagated.

Although this method of breeding has certain advantages for the breeder it has obvious disadvantages in that vast numbers of hybrid seedlings have to be raised in the search for improved types. Potatoes, however, show a high degree of sexual sterility of one form or another in the great majority of varieties, and one of the great handicaps in potato breeding has always been the impossibility of using some of the best varieties for hybridising purposes, and the consequent restriction of the parental material as far as commercial varieties are concerned, to those which show sexual fertility. This difficulty has been lessened in recent years by the raising of sexually fertile seedlings which can be used for further breeding.

Inter-Specific Hybridisation. In spite of the great range of genetic variability that is available in the varieties of many cultivated species, the use of inter-varietal hybridisation may offer definite limitations for the improvement of valuable characters. It may also be the case that the desired expression of certain characters is not found in one species, and further improvement is held up through lack of the required parental types, or by a restricted range of variability which has been tried in various combinations by hybridisation within the species. When these conditions are met it may be necessary to turn to allied species for some desired character or characters, and to try to incorporate the required character, or induce a wider range of variability, by resorting to inter-specific hybridisation.

This method of breeding has been used with success in several crops including wheat and oats, and has been the basis of the attempts to breed potatoes resistant to late blight (*Phytophthora infestans*). In both wheat and potatoes there is a range of species related to the important cultivated species (in which are included the most widely grown varieties) showing a degree of disease resistance not found in common commercial varieties. In many cases of inter-specific hybridisation there are difficulties concerned with sterility often associated with different chromosome numbers of the species concerned. Special techniques are often required for the most effective use of inter-specific hybridisation, and in the case of wheat, new species have been synthesised by hybridisation and artificially doubling the chromosomes to overcome sterility and make further hybridisation possible.

The development of the technique of inter-specific hybridisation adds considerably to the possibilities of artificially creating new types which would be quite impossible under natural conditions. The collection of a wide range of forms and species that do not exist together naturally, or in any one area of cultivation, is now a fundamentally important part of plant breeding. The large number of species allied to the cultivated potato offers a great range of genetic variation, and certain characters would be of great value if they could be introduced to cultivated varieties suitable for this country. Several expeditions have visited the centres of the occurrence of these wild and cultivated forms of *Solanum*, which occur in Central and South America, to collect potentially useful species for breeding. Other expeditions have visited the Iberian Peninsular and North Africa to collect grass species such as tall fescue and cocksfoot, while the centres of variation of the principal cereals, and of tropical crops such as bananas, have been similarly closely studied.

Inter-Generic Hybridisation. In the same way that inter-specific hybridisation offers a means of effectively combining new characters normally outside the scope of hybridisation within one species, so does inter-generic hybridisation present the possibility of even wider combinations. There is, however, less scope for inducing generic combinations because of the difficulties in the actual technique of hybridising. The method is, however, being used in the related genera which include wheat, rye, and the couch grasses (the genera *Triticum*, *Secale* and *Agropyron*). These hybrids have been produced with two primary objects—the breeding of wheats with the capacity to survive extreme climatic and soil conditions (*Triticum* x *Secale*, and *Triticum* x *Agropyron*), and perennial wheats and forage grasses suitable to land reclamation work (*Triticum* x *Agropyron*). Much hybridisation has also been effected between *Triticum* and the closely related genus *Aegilops* (Goat grasses), and it has been possible to transfer rust resistance from this genus to wheat by the use of X-radiation. Special techniques have been developed for the transfer of whole chromosomes or parts of chromosomes of both *Secale* aand *Aegilops* to cultivated wheat, and this synthesis of what are called chromosome substitution, and chromosome addition, lines is offering a new and more promising means of exploiting intergeneric hybrids of wheat breeding.

Back-Crossing. " Straight " hybridisation, involving the application of only one parental crossing, is in certain cases ineffective in bringing about the type of character recombination that is desired, and it may be necessary to resort to back-crossing to one or other of the parents, or even to more than one different parental type. The back-cross method is used particularly, for example, when the object is to transfer a single character like disease resistance from an otherwise undesirable form to good commercial stocks and it has been applied successfully to breeding disease resistance into cereals and potatoes. The method is applicable to inter-varietal crosses, as has been done in transferring resistance to mildew (*Erysiphe graminis*) from one barley variety to another, or to inter-specific crossing as in the case of late-blight in potatoes. In the latter case, where domestic varieties are hybridised with a wild species which possesses blight resistance (*Solanum demissum*) a succession of back-crosses to different commercial varieties may be practised to restore the desirable domestic characters to hybrid seedlings which have been shown by test to be resistant to blight as a result of the first cross.

Multiple or Poli-Crossing. In both self- and cross-pollinated crops crossing involving more than two parents may be used. The material may be handled in various ways, but a common way in self-pollinated crops is to make a number of "straight" crosses and then hybridise the first generation hybrids of these crosses in various combinations. The object in all cases is to introduce the "blood" of as many forms as is considered practicable in order to provide character combination for selections which would be impossible by a single cross.

Limitations of Hybridisation. Although hybridisation offers the most obvious and practicable means of creating new variability and new character recombinations, it is important to realise its limitations as a method of improvement, particularly with regard to bringing about character recombinations. In attempting to mould new plant types showing enhanced economic characters, the breeder often finds that it is impossible to select from the hybrid populations the particular combination for which he is looking. The reason for this may be genetic linkages or repulsions, or it may be regarded as due to a fundamental physiological incompatibility of characters which make it impossible to accumulate in one individual the highest expression of a combination of certain characters. An example of this may be seen in a character complex like yield which is dependent for its expression on a number of morphological characters and certain physiological characteristics. The particular yielding capacity of different commercial varieties depends on certain combinations of all the yield characters, and these combinations are not necessarily the same in all varieties—indeed they rarely are. When two varieties showing different yield characters are hybridised, it does not follow that it will be possible to select in the hybrid generations individuals showing a combination of all the highest expressions of the yield characters. In fact, it has been shown that this is impossible, and all the breeder can do is to select the best combinations available.

This example shows that hybridisation is not simply a means of mechanical re-shuffling and recombination of characters, and that the breeder cannot produce new types at will. The living plant is a delicately balanced organism and there are limits to what can be effected in attempts to concentrate desirable economic characters in one individual. It was a lack of appreciation of this fact that led the early Mendelian hybridists to express such extreme optimism on the future of plant breeding by the application of "Mendelian methods" of breeding, an optimism which led some investigators to state that the problems of breeding in animals and plants had been solved. Nevertheless, hybridisation followed by judicious selection and testing has been the means of effecting far-reaching and fundamental improvements in plants, and when properly applied offers the most effective means of organised and systematic progress in crop husbandry through crop improvement.

Chromosome Doubling. The artificial production of polyploids by treating individual plants with the drug colchicine is an attempt to bring about artificially what is known to have occurred under natural conditions in the evolution of cultivated plants. Straightforward doubling of chromosomes, i.e. the production of *autotetraploids*, has been achieved in many cultivated plants by this method, but so far the results have not been particularly valuable as far as crop plants are concerned. Such autotetraploids often show " gigantism " in certain characters, but this may have no practical value to the crop. In sugar beet and fodder beets the most promising results at present appear to be in hybridising the artificial tetraploid with the normal diploid. The resulting triploids have been found in certain cases to produce higher yields of dry matter than either the diploid or the tetraploid. In sugar beet ' polyploid ' varieties are now available, these being mixtures of tetraploids, diploids and the triploid hybrids between them. Tetraploid forage crops, such as alsike clover, have also been produced, as have tetraploid barleys, but none has shown any special virtues as far as the agriculture of this country is concerned.

The alternative use of chromosome doubling in plant breeding is in wide crossing where the hybrid is sterile. By doubling the chromosome number a fertile *allopolyploid* or *amphiploid* is produced and such forms can be used for further experimental work. These amphiploids have been produced in considerable numbers in crosses between different species of *Triticum*, and in crosses of *Triticum* with *Aegilops* and with *Secale*, and they can be used as ' bridging ' forms to hybridise with cultivated wheats or as the starting point for the production of the chromosome substitution and addition lines already mentioned.

Mutations or " Sports ". Many well-known varieties of certain cultivated plants, for example potatoes and some fruits, have arisen by spontaneous changes in the chromosomes and genes resulting in the development of new characters of commercial value. Attempts have been made in many plants to accelerate the rate of mutation, or to induce mutations artificially, by exposing plants to X-rays, extremes of temperature, chemicals and similar sudden shocks likely to cause chromosomal irregularities or aberrations. Mutations have been obtained in this way, but with few practical results as far as useful or improved types is concerned. This technique for the breeding of agricultural crops, as distinct from the production of novelties in horticultural ornamentals, needs considerably more research before it could compete with standard hybridisation methods. It will be necessary to devise methods of increasing the rate of mutation and also to obtain a better control over the means of directing the type of mutation before the technique is really economic. However, it is obviously possible to visualise circumstances in which ' mutation breeding ' could be effective in solving a special problem in improvement, but more research is needed for a better definition of the most appropriate techniques.

THE FUTURE OF PLANT BREEDING

During the many thousands of years during which plants have been cultivated, improvements have consisted, until recent times, in the cultivator taking advantage of new types which have arisen naturally. The mere act of cultivation, with the growing of plants in large numbers and their careful tending with the selection of good types for seed, are contributory causes to the origin and survival of new forms. The growing of different varieties, or mixtures, adjacent to one another offers the means of natural hybridisation with the production of new types, while any new form arising by natural mutation is likely to be perpetuated artificially if it has any value.

But the development of organised plant breeding on an intensive scale seeks to accelerate the natural means by which diversity and new types arise, although the breeder has necessarily to use these natural means, as in artificially controlled hybridisation, selection, polyploid induction and mutational changes. The greater scope in planned breeding is due to the use of a wider range of material, the directed hybridisation and selection, and the use of scientific aids to effecting combinations that would not occur naturally, as well as in using selection methods and testing with varying degrees of precision. In addition to better-controlled and better-directed methods of breeding in themselves, the opportunity of producing improved types is enhanced by a greater understanding of the utilisation of the product by the consumer. The scientific basis of quality, the precise requirements in processing agricultural products, and the underlying principles of the feeding value of plant products gives greater scope to breeding and enlarges the whole aspect of plant improvement. But in the final analysis, it is the interests and requirements of the grower that must receive the lion's share of the breeder's attention, and it is towards plant breeding that attention can be focused for important contributions to the efficiency of crop husbandry.

Chapter XVI

ANIMAL BREEDING

THE general aims of animal breeding are the same as those of plant breeding, to improve the efficiency and productivity of the stock and, if possible, to ensure that the level of performance in the next generation is at least as good as, and preferably better than, that shown by the present generation. The concept of bringing about improved performance in the offspring as compared with their parents is fundamental to the whole idea of constructive livestock husbandry ; and in so far as performance is affected by genetic conditions, the same basic principles as those applied in plant breeding are relevant to animal breeding. Also, as has been pointed out in the case of crop plants, more complete knowledge of the physiology and development of the characteristics which build up performance is needed, as well as of the qualities of the various animal products which influence consumer demands, in order that the directions along which improvement is required can be more clearly defined.

Some of the early " improvers " of farm livestock tried to assess demands so that they could discover the ways in which their existing stock fell short of requirements and thus how and where improvement was needed ; for instance, it is on record that Ellman, to whom the development of the improved Southdown sheep is due, studied closely the joints and their relative weights and prices in butchers' shops as a means of deciding the most desirable carcase conformation and weight at which to aim. The aim determined, the early breeders developed, largely by trial and error, selection and breeding methods which they thought would achieve the desired progress. The discoveries of the principles influencing the processes of reproduction and inheritance have explained the results of the early improvers' efforts but they have not yet caused any spectacular or radical change in the methods used. Only in recent years have deliberate applications of the scientific principles begun to make much impact on practical procedures in animal breeding and that mainly in the direction of making selection methods more accurate and breeding methods more precise.

LIMITATIONS ON ANIMAL BREEDING METHODS

Some of the major differences between plants and animals in terms of reproductive and genetical processes have been indicated in Chapter XV. These differences affect the selection and breeding systems which can be used. Farm livestock are unisexual, so that self-fertilisation or the development of " pure lines " (pp. 468, 471) are impossible. Sexual reproduction continually sets the stage for genetic variation to be expressed ; mating is between animals of the same species (except in such cases as mule breeding) so that sterility and incompatibility problems in the previous sense do not arise ; nor does hybridisation, in the narrow sense of crosses between species, occur to provide variations on which natural or other selection can work. Yet deliberate production of crosses between breeds of the same species to give hybrid stock which are not intended for subsequent further breeding has become a widespread commercial practice, e.g. in the poultry industry. This development is more appropriately discussed later as a form of " crossbreeding ". Polyploidy also does not occur in farm stock, and since there are large numbers of chromosomes involved in each species the chances are remote of linkage and crossing-over being exploited in recombinations of genes ; only very few cases of linkage in livestock have as yet been discovered.

A major significant difference between plants and animals which severely restricts the scope of operations in animal breeding lies in the forms of populations of individuals or communities. Very large numbers of plants are usually distributed on relatively small areas, whereas animals are more widely spread in fewer numbers in smaller breeding units. Even a numerically large " breed ", say of sheep, can total many fewer individuals than one particular field of crop plants. Except in the case of numerically very small " breeds ", the head of stock of the " breed " owned by, or available to, any one breeder amounts to only a small fraction of the total of the " breed ". Moreover the breeding units—herds or flocks—are usually dispersed over a variety of management systems and environments. The reproductive rate is low, except in poultry and pigs ; parents have very few offspring, while in plants a new population can be built up very rapidly from a small amount of parental material.

These considerations imply that :

(1) in animals, more parents have to be kept to provide enough offspring to keep the " breed " going, whereas in plants whole populations, e.g. varieties, can be rapidly replaced by the descendants of a small amount of parental material ;
(2) selection of parents in plants can be much more rigorous ;
(3) there is less uniformity of aims in animal breeding and less rationalisation or consistency of methods and objectives ;
(4) progress in any direction is slower and " improved " breeding material is less rapidly spread into commercial practice.

It takes a considerable time for the individual animal to develop sufficiently to give a return to the breeder. During this time the growing animal is exposed to differing environmental conditions. For example, a lamb ready for slaughter at four months old has spent more than half its life as a foetus ; for about 3 or 4 weeks after birth it has been entirely dependent on its dam's milk for its nutriment ; the rest of its life has been spent on a diet in which milk becomes progressively less important and grazing, and perhaps supplementary feed, more significant. In dairy cattle, the earliest actual measure of milk performance that can be made is that of the first lactation ; if a heifer is mature enough for first mating at 18 months old, then she will be over twice this age before her first standard lactation is ended. During this time, the varying and complex series of feeding, management and environmental conditions under which she has been reared and kept have affected her physiological development and the degree to which her genetic potential for milk production is expressed. The animal breeder has continually to try to control, or to allow for, the phenotypic differences due to environmental influences before he can distinguish the genotypes.

BREEDING MATERIAL: VARIATIONS

As in plants, the breeder has to make use, for the most part, of the variations already available in his stock as a basis for improvement, or to bring about recombinations of genes to provide further variation on which he can work. The reservoir of breeding material—and genes—from which he can draw is made up of " breeds ", varieties, or types of the species. Unfortunately, none of these terms, especially " breed ", has a clear and specific meaning, except in so far as it may denote a group of animals—a sample of the whole range of variation of the species or race—which possess certain highest common factors of characteristics so that they can in general, or on average, be distinguished more or less clearly from other groups.

All breeds, say of cattle, have some characters in common ; all produce milk, all put on some flesh and lay down some fat at some stage or other : but the yields of milk and its butter fat content vary from animal to animal, and from one herd to another, within the breed as well as from breed to breed. None the less, some breeds have characteristically high yields or low yields, high *versus* low butter fats and so on. No breed is uniform in itself in respect of the performance characters which typically distinguish it from others, the ranges of performance levels overlap to some extent. While it is proper to say that the Jersey is a high butter-fat breed of relatively low milk yields as compared with the Friesian, this does not mean that all Jersey milk is invariably high in butter fat content or that all Friesians give relatively high milk yields ; it means that the gene combinations favouring one or other main character are differently distributed throughout the two breeds. Moreover, these two breeds are distinguished by differences in other characteristics such as coat colour, and body conformation or type ; the defined black and white colour pattern of the Friesian does not occur in the smaller framed, more extreme " dairy type " Jersey. Yet colour and pattern are not uniform within either breed.

Breeds are often distinguished by characters which are inherited in a fairly simple Mendelian manner with the controlling genes distributed throughout the breed. For example, the Aberdeen Angus is typified by the simple dominant polled and black coat characters (as opposed to the recessive horned and basic red characters) while the Hereford breed is marked by its dominant white head pattern on its recessive red body colour.

Where colour patterns, as in Hereford cattle or in Saddleback pigs, can be regarded as " breed labels ", the precise extent or distribution of the pattern may vary between individuals because of the action of modifiers, which may be subject to selection : in such cases the conformity to breed standard or trueness to type of a strain may be interpreted as indicating the consistency or " purity " of its selection and breeding.

In contrast to such simple genetic situations, the inheritance of most performance or productive characters is more complicated. There is overwhelming evidence that physiological characters such as growth rate, fleshing, milk yield, etc., depend upon the action of large numbers of complementary genes, many genes with additive effects, or complex gene interactions, so that they are expressed as levels of " quantitative " rather than " qualitative " inheritance. Variations in performance tend to be continuous, grading smoothly throughout the range and not being exhibited in marked steps or jumps from one category to another so that the effects of a single gene or of a few genes cannot be detected. During the development of a breed these quantitative characters have been built up to give the breed its characteristic performance levels ; and where a definite breed label is involved this has sometimes led to the idea that the label gene itself may have some direct or appreciable effect on performance type. For example, in the Aberdeen Angus breed its polled black labels are now associated with the conformation, growth, and fleshing abilities which have been developed in it ; in the Hereford, the white-faced pattern is associated with the other breed characters of beef conformation and growth. Yet in other breeds, the general beef performance characters and conformation have been built up under other labels, e.g. in the Sussex and Devon with their whole red coat colours, or under no specific coat colour pattern as in the Beef Shorthorn, where it ranges from white through the various roans to red.

Where the breed labels are of dominant characters, such associations are used in the " colour marking " of crosses between breeds. In the cross between the Hereford and the Welsh Black, the offspring are black with white faces. Along with the dominant gene for white face some of the genes affecting the physiological development of beef characters are also brought in from the Hereford.

The offspring of a cross between Aberdeen Angus and, say, Ayrshires are basically black and polled, with more beef potential than that found in the Ayrshire, but with less milk yield potential ; similarly, Aberdeen Angus × Friesian animals exhibit the effect of the polled gene as well as those of the genes influencing earlier fleshing.

Again, in sheep, the speckled brown faces of lambs out of white faced ewes such as Cheviot, Scots Half-bred, or Welsh Mountain indicate not only that their sires were of a dark faced breed such as the Suffolk or Hampshire but also that they must have some measure of improved genetic potential for growth and development for lamb production. If, however, such crosses (breed hybrids) were to be interbred, segregation of the genes affecting all characteristics would be expected, resulting in a wide variation in the second crossbred generation.

Another aspect of these breed label situations must be noted. Blacks do not occur in the basically red breeds, but recessive reds may appear in the black breeds if and when their parents are heterozygotes ; the appearance of a red calf at once incriminates both its parents as heterozygous for the black-red pair of genes and the frequency of recessives indicates the frequency of heterozygotes in the breed or strains within the breed. (The same applies in the case of inherited defects.) But so long as the contrasting qualitative genes have no major effects on the quantitative characters, there is no other difference in genetic potential for performance between the animals showing the recessive character and those which conform to the breed standard ; thus, in every other respect red and white are similar to black and white Friesians or red to black Aberdeen Angus.

In general, the simple gene situations are not affected by differences in environment, whereas the complex quantitative characters respond to varying degrees to external influences. This means that among the total character variation with which the breeder can deal, some of it is largely due to inheritance, while some is attributable to environmental conditions. By the use of modern statistical methods it is possible to analyse the relative amounts of phenotypic variation to genotype, to genotype-environment interactions, and to environment : that is, to estimate the " heritability " of the various performance characteristics and thus gain some idea of the procedures to be used by the breeder to manipulate the genetic material in the direction of improved or more reliable and efficient performance.

The estimates of heritability so far made do not give a complete coverage of all the characters which contribute to the economic worth of farm stock ; also, the estimates vary among themselves for the same character within any one type of stock.

Without attaching too much importance to any particular estimate, it is possible, however, to compare grades of heritability in respect of different characters, and to distinguish between those where environmental effects are so important that they can override or mask the genetic variation and those in which the genetic effects are more significant. The former groups are of low, the latter of high heritability.

Among dairy cattle, milk yield is of lower heritability than butter fat percentage ; birth weight in beef types and the rate and economy of gain of live weight after weaning are more highly inherited than conformation grade at weaning, and the dressing-out percentage at slaughter higher than carcase grade.

In pigs, the carcase characteristics of length, area of eye muscle, backfat thickness, and percentages of cuts in the carcase weight are all of very high heritability, with body and leg lengths in the live pig less heritable though still high, and weight at five to six months relatively high, as compared with live conformation score, numbers farrowed and weaned, and weight at weaning which are generally of low heritability.

In sheep, there are indications that the characters in the relatively low heritability group include type or body conformation and multiple births, while wool staple length and fibre diameter and face covering are in the high group ; body weights at birth, weaning and twelve months, fleece weight and milk yield are of intermediate or moderate levels of heritability.

BREEDING METHODS: SELECTION AND TESTING

As in plant breeding, selection of the individuals which are to be the parents of the next generation forms the basis of any breeding programme; in animals this means choice of both sire and dam. The aim is to choose parental genotypes likely to give gene combinations of equal or of higher potential performance in their offspring.

Selection. Selection on phenotype, or appearance, can pick out animals showing desirable characteristics and so enable collections of foundation stock to be made. It cannot identify with certainty those individuals which are likely to be successful or consistent as parents, except where simple recessive gene combinations are wanted. In such cases, e.g. as when a sub-breed of red and white coat colour is to be started from recessives occurring in a normally black and white breed, no mistake can be made by breeding from them. In all other cases, a progeny test is necessary to determine the genotypic constitution of the parents.

Progeny Testing. In order that progeny testing can be carried out so as to provide adequate information on parents and progeny, the actual breeding, i.e. the *pedigree*, of the stock must be properly recorded. Also, standard methods of assessing or measuring and recording their performance must be available, such as those for milk yields and butter fats in dairy cattle, i.e. *performance testing*. For this purpose much remains to be done in other classes of stock, and for other performance characters, before it will be possible for breeders to have access to realistic data which they can use in selection.

Where records are available, many cattle breed societies have been able to add on to their pedigree registration schemes further information regarding superior performance by individual females which have achieved certain production standards, in the forms of "Registers of Merit" or "Advanced Registries", and so on, sometimes coupling these with conformation type categories. These systems of "selective registration" indicate to other breeders the animals, the herds in which they have been bred or recorded, and their sires, which may be suitable as sources of breeding material. But they lack specific information on the levels of management and feeding under which the records have been attained, and so are difficult to interpret for comparative purposes.

Progeny testing is expensive in terms of the numbers of animals required. Even for recessive defects, where the tests for possible carrier or heterozygous sires can be done in the three main ways of mating, (*a*) to recessive females, where the defect is not associated with infertility, (*b*) to females known to be carriers, or (*c*) to their own daughters, it is reckoned that at least 5, 11, or 23 offspring, respectively, are required for a reasonably satisfactory chance of a defective one appearing and so proving the sire heterozygous. Where the females are more prolific, e.g. in pigs and poultry, fewer of them are needed to supply the necessary numbers of progeny per sire. Furthermore, early testing of sires is not possible if performance in their progeny cannot be assessed until they have grown to production, e.g. in milk or beef production. For such reasons, progeny testing schemes usually require large breeding units or co-operative undertakings before sufficient numbers and resources are available.

Testing Stations. Progeny testing is most necessary in respect of characters of low heritability, and the problems arising from environmental influences have led to two main procedures. The first method involves testing stations at which the performance of samples of the progeny is measured under standard conditions of housing, feeding, and management, so that progeny groups of different sires can be compared. It is most extensively used for pigs and dairy cattle, and lends itself to increasing use for beef cattle, but at best can only include progeny of a limited number of sires. For pigs, the samples are of the order of four piglings per litter ; for dairy cattle, the groups of offspring are generally chosen so that fifteen or so will calve down within a short period of time to begin their first lactations.

The same standard environmental system is also useful for testing characters of higher heritability (where phenotype more closely reflects genotypic merit), e.g. live weight gain in beef type bulls, or young boars, so giving a basis for the direct selection of the individuals themselves, but without information on carcase qualities. Indirect information on these can, however, be obtained from the performance of full brothers and sisters (" *Sibs* ") not wanted for breeding ; e.g. " sibtesting " of a young boar involves taking some of his sibs of the same litter through to slaughter under standard conditions and recording their carcase scores, in addition to their rates of gain, food conversion, etc.

Contemporary Comparison. The second, alternative, method provides for larger groups of offspring being recorded under farm conditions for comparison with progeny of other sires kept under the same wide range of environment. The basic assumption here is that the influences of management and environment are at random for sire groups in different herds over any period of time, so that " contemporaries " are similar in relation to their physiological age and condition. This method of contemporary comparison needs widespread performance recording schemes, and thus has so far been developed mainly with dairy cattle ; it is especially applicable where sires are widely used, as is possible with artificial insemination.

In the British systems, the first lactation yields of a bull's daughters are used along with those of other bulls' daughters in the same herds at the same time, and the herd and breed averages, to derive a " Relative Breeding Value " for each sire ; these can be used to distinguish between high and low value bulls. The New Zealand Sire Survey system uses similar data to obtain an " expected daughter average " in terms of mature butter fat yield, which indicates if, and by how much, a bull's daughters may differ from those of an average bull.

BREEDING METHODS: MATING SYSTEMS

The distribution and recombination of genes are affected by the ways in which the parents selected are mated together. The mating systems vary in their use and in their results according to the degrees of genetic relationship between the parents involved. All members of a breed have some parts of their genetic constitutions in common and so are remotely related ; mating within a breed or type is generally called *breeding pure* (or, within the registered section of the breed type, *pedigree breeding*). Some groups are more closely related to each other (families or strains) than the rest of the breed ; in this sense the closer the relationship, the greater the likelihood of closer similarity of genotypes. Mating of close relatives, brother-sister, sire-daughter, etc., constitutes *inbreeding*, but in animals this, as a system, is rarely carried on over enough generations to set up anything approaching the highly inbred lines found in plants. It is usually carried out in a milder form among less closely related members of a " family ". In so far as it tends to increase the homozygosity of many gene combinations it can lead to greater uniformity, but also, as undesirable gene combinations also accumulate, to some deterioration.

Another form of this system is *linebreeding*, where successive matings increase the relationship to a favoured animal, without closely "inbred" matings, and tend to increase the chances of genotypic similarity to it. It can be regarded as a special form of " back-crossing " to an individual, or strain, within a breed ; in a less intensive way it is also used in " grading up ", e.g. of non-pedigree animals by successive matings to pedigree sires. The basis of this process is now being widely used (as in plants) to introduce fresh genes into a breed ; for instance, many horned cattle breeds are now developing polled strains from initial crosses with polled animals of another breed, followed by backcrosses to reconstitute the original breed genotypes for all other characteristics.

Where the parents are more distantly related, or unrelated, as between breeds, the system is *crossbreeding* or *outcrossing*, with similar effects to those described under hybridisation in plants (see p. 472). It has been widely used in the development of livestock breeds, an interbreed or inter-variety cross being followed by selection and mild forms of inbreeding among the descendants of the first generation hybrids to establish fresh gene combinations in the " new " breed. In this process any " hybrid vigour " which may be shown in the first cross is subsequently lost but deliberate crossbreeding to give hybrid animals for slaughter is a common practice in commercial stockbreeding, e.g. in lamb production, in pigs, and in beef cattle. The first generation crossbred females are sometimes mated back again to sires of one or other parent breed, or more commonly of sires of yet another breed in continuation of this method of combining attributes from different sources and getting fresh states of " heterosis " in each crossbred generation.

FUTURE PROSPECTS IN ANIMAL BREEDING

The scope for future developments in animal breeding extends into the same broad areas as those indicated for plant breeding (see p. 478), especially in the directions of increasing the precision of selection techniques and, from further knowledge of the physiological processes of reproduction and performance, of accelerating the effects of methods of manipulating genetic situations to bring about improved production to meet continually changing demands.

Artificial insemination has already proved a powerful technique in altering rapidly the breed, and the genetic, constitution of dairy cattle populations ; for spreading widely and quickly the effects of using highly selected sires ; and for introducing new genes. Its further extension in other species will offer similar opportunities to breeders.

Techniques such as ova transplantations to foster mothers hold out prospects of improved production and testing methods.

Progress is already being made in the direction of earlier testing of sires, as by semen collection from young dairy bulls, and also of measuring tissue proportions (fat, lean, bone) in meat animals while they are still alive. Increasing knowledge of the early stages of fleece development and growth in the young lamb holds out distinct possibilities of early selection for adult fleece characters.

Studies on genetic correlations of characters will reveal how far selection and breeding for one particular set of characteristics may affect the trends of changes in others ; more gene linkage groups for important performance characters may be identified and new mutations discovered. More heritability estimates will be acquired and made more accurate. All these should contribute to greater precision in the use of the breeding methods themselves.

Chapter XVII

THE STRUCTURE AND FUNCTIONS OF THE ANIMAL BODY

CATTLE, sheep and pigs, which are the principal large farm animals, are all mammals. The mammals are the highest of the five classes constituting the *Vertebrata* or animals with backbones. The other classes in descending order are the birds (which include the domestic fowl, another important farm animal), reptiles, amphibians and fishes.

Mammals are warm-blooded, hairy animals which suckle their young and which, with only a few exceptions, undergo a period of embryonic development within the womb of the mother. Two of the exceptions are the duck-billed platypus and the spiny ant-eater from Australia, and these form the lowest division of the mammals ; they can be described as egg-laying mammals. A covering of hair is characteristic of mammals and distinguishes them from other vertebrates, but in some species the hair covering is scant. Most of the mammals are quadrupeds, but in some aquatic mammals, e.g. seals, whales and dolphins, the hind-limbs are modified, reduced or absent.

The birds are also warm-blooded, but the characteristic hair covering of mammals is replaced by feathers. The hind-limbs are well developed, but the fore-limbs have become adapted as wings used for aerial flying : in the domestic fowl this power of flight is greatly reduced. The birds are egg-laying animals and the embryonic development of the chick takes place within the egg.

The study of the structure and form of the body is known as *anatomy* ; it may represent a study of parts visible to the naked eye but may also involve more detailed microscopic studies (*histology*). It is quite as important to study the uses and functions, or *physiology*, of the various organs of the body. Further examination of the actual nature of the chemical reactions occurring as the body functions proceed can be described as the study of *biochemistry*.

The development of an animal can be divided into two parts, an early phase of development within the body of the mother (mammals) or in the egg (birds), and a phase after birth when the animal is free-living. The former can be referred to as the pre-natal and the latter as the post-natal phase.

THE CELL

The body of any higher animal such as a man, an ox or a fowl, is composed of a number of microscopic structural units or cells built up in various ways to produce tissues and organs. The cell is the smallest unit of living matter capable of leading an independent existence, and has the power to divide and produce other cells of its own kind. Some of the simplest animals, e.g. *Amœba*, consist of a single cell, and bacteria, which are looked upon as plants, are probably the smallest

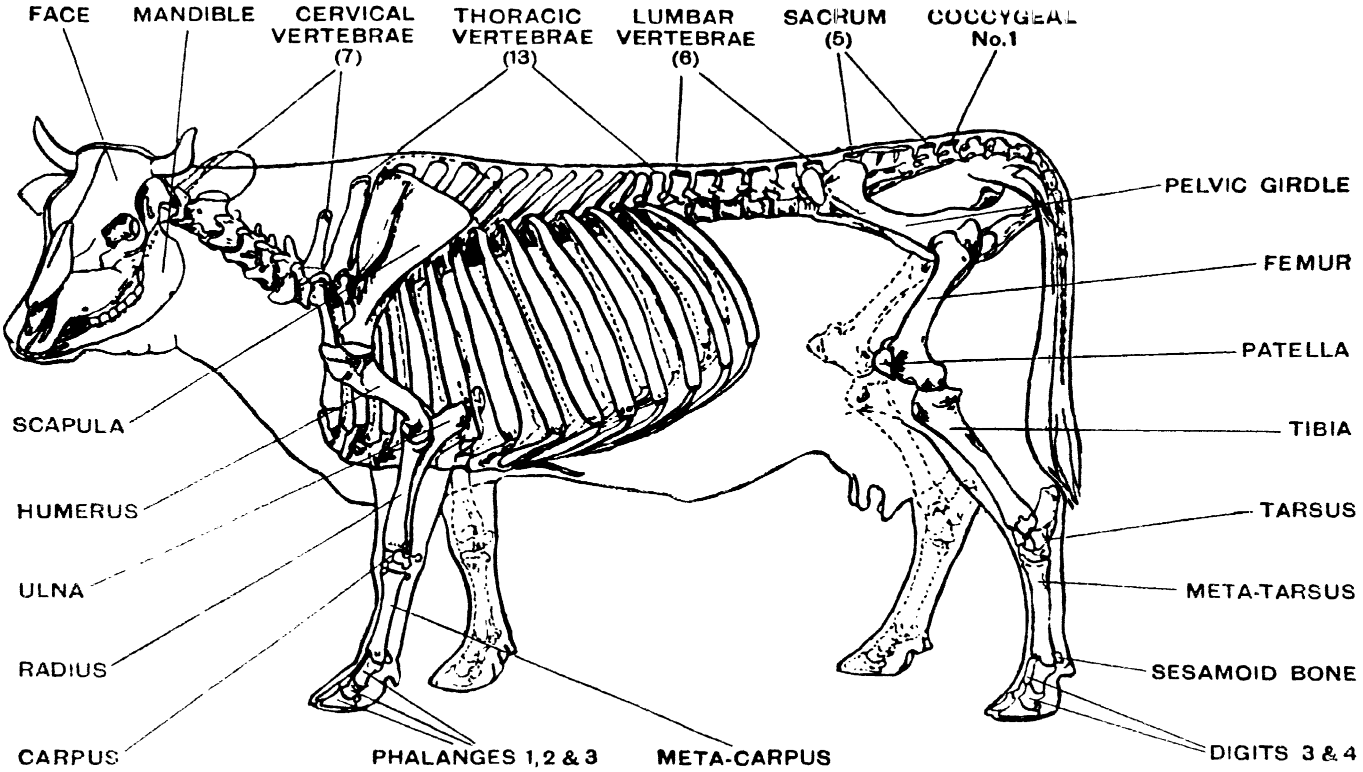


FIG. 97.—SKELETON OF THE COW.

of all single-celled (unicellular) organisms. The viruses, which are even smaller than bacteria, can only reproduce when they are inside living cells and therefore cannot themselves be regarded as true cells.

Each cell has two main parts. In the central area is the *nucleus* which is the organising centre of the cell and contains the chromosomes (see Plate XXXI). Surrounding the nucleus is a variable amount of *cytoplasm*, and the whole cell is contained within a delicate cell-membrane. The cellular material is collectively referred to as *protoplasm* and this complex material is the physical basis of life. Life itself is dependant on the continuous bio-chemical activities (metabolism) taking place within the protoplasm, and the protoplasm is not merely a receptacle in which these activities occur but is a dynamic participant. The activities consist of innumerable chemical reactions and, as they take place, the actual nature of the protoplasm changes ceaselessly. Upon these diverse activities the phenomena of life depend.

When normal cell-division occurs there is an exact division of the material of the nucleus so that each cell has a nucleus which is an exact replica of that in the cell from which it was derived. Also, during division there is a sharing of the cytoplasm between the parent cell and its offspring. However, not all cells are identical and different types of cells become adapted for different functions in the body.

The body of a higher animal develops from a single cell, the fertilised egg or *ovum* which is derived from the union of two specialised cells called *gametes*, one from the male and one from the female (see p. 463). The fertilised ovum is the parent cell of the future offspring and divides first into two cells, then each of these divides again to produce four cells and so on, until the many millions of cells which constitute the animal body are produced. It is not strictly true to say that the body is completely composed of cells, for there is material deposited between the cells (inter-cellular material) which is important in maintaining the structure and functions of the body.

An examination of different cells in the body reveals that they are by no means all identical as might be supposed from the description of cell-division above. During development the animal has the power to produce different families of cells of different shapes and sizes which are adapted to their functions in the body. An examination of cells from nervous tissue, bone and muscle will demonstrate just how great these differences can be. The mechanism by which these different types of cells are produced from a single parent cell is obviously complex and begins at a very early stage of pre-natal life.

The process of cell-multiplication continues throughout the period of growth of the animal and to a lesser extent during adult life. In adult life cell-multiplication is largely concerned with the repair of tissues as cells age and die, and as this process slows down the animal itself eventually ages and dies.

THE ORGANISATION OF THE ANIMAL

In a simple unicellular animal like *Amœba* the single cell is extremely versatile in that it carries out all the functions of the body. Living in a watery environment, the cell can absorb oxygen and take in food

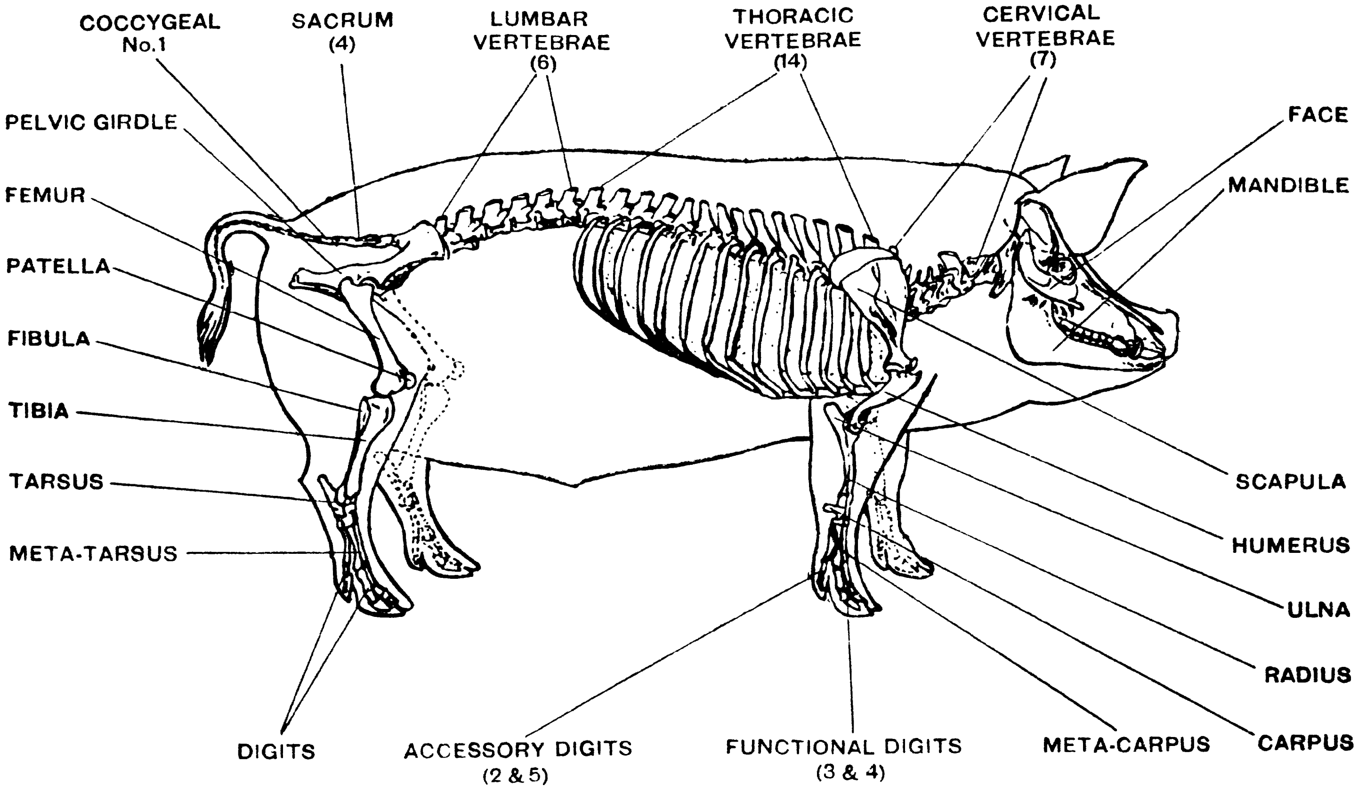


FIG. 98.—SKELETON OF THE PIG.

from the surrounding water and excrete waste products into it. As an animal increases in size the simple existence led by *Amœba* becomes impossible and there is a great increase in complexity of structure. Most of the body is composed of soft tissues and requires a structural framework, the skeleton, around which the soft tissues can be built. A muscular system is present which provides power for locomotion and for other functions too, such as the movement of food through the body. The animal must also have some means of transmitting messages to all parts of the body so that functions such as movement are co-ordinated ; this need is fulfilled by a complex nervous system with the brain as its most important part. To carry out the essential body functions such as digestion, respiration, excretion and reproduction, highly specialised parts of the body have been developed. Also, to transport food and oxygen to each cell of the body and to remove waste products from the cells, an extensive circulatory system has been developed.

A knowledge of the structure and functions of these systems within the body is not merely of academic interest but can be of direct help to the agriculturist in the production of animal products in the most efficient way.

THE SKELETON

If the body were divested of all its soft parts there would remain a framework of bone, gristle (cartilage) and fibrous tissue, the skeleton, which supports the body and may, as in the case of the skull, have a protective function.

The skeleton can be divided into two main parts, the *axial skeleton* and the *appendicular skeleton.* Included in the axial skeleton are the skull, the vertebral column or backbone (which includes the bones of the tail) and the ribs and sternum. An important feature of the vertebral column is that it forms a long tube through which passes an important part of the nervous system called the *spinal cord.* The appendicular skeleton consists of the shoulder blades (which together form the pectoral girdle), the pelvic bones (which form the pelvic girdle) and the limb bones. No detailed description of the skeletal parts is given here, but the skeletons of the cow, pig, horse and bird are illustrated diagrammatically in Figs. 97, 98, 99, and 100.

One point of terminology is worthy of mention at this stage as it can lead to confusion. In farm animals the junction in the fore-limbs between the humerus and the radius and ulna is referred to as the elbow, as in the human. However, the junction between the radius and ulna and the carpals, which is often called the knee in farm animals, is equivalent to the human wrist. Similarly the junction in the hind-limbs between the tibia and fibula and the tarsals is known as the hock, which is equivalent to the human heel.

The bones of the young animal are not fixed together but have a pad of pliable cartilaginous tissue between their surfaces of contact. This arrangement gives the skeleton a certain resilience and allows for the growth of individual bones as the skeleton develops. Once skeletal development is complete many of these pads are replaced by bone and the bones gradually become fixed together. In bones which

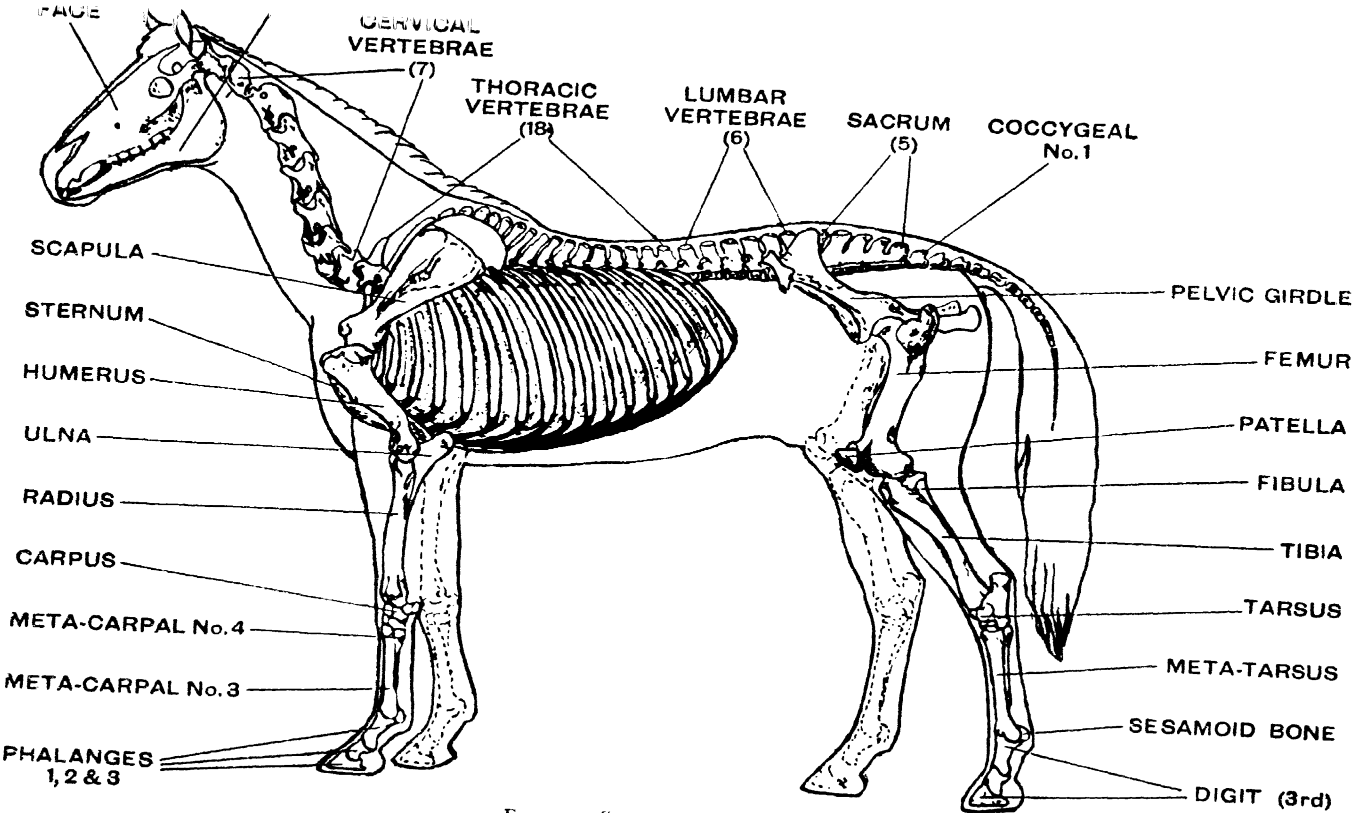


FIG. 99.—SKELETON OF THE HORSE.

move upon each other, as in the limbs, a layer of cartilage covers the end of the bone and there is a secretion of a lubricant fluid into the joint so that friction is reduced to a minimum. These joints do not ossify, and so the power of free movement is retained although in aged animals friction increases and movement becomes " creaky ".

Microscopic examination of bone or osseous tissue reveals two types of bone in the long bones of the limbs. The shaft of the bone consists of a tube of hard compact bone, whereas the end or *epiphysis* is composed of spongy bone covered by a thin shell of compact bone.

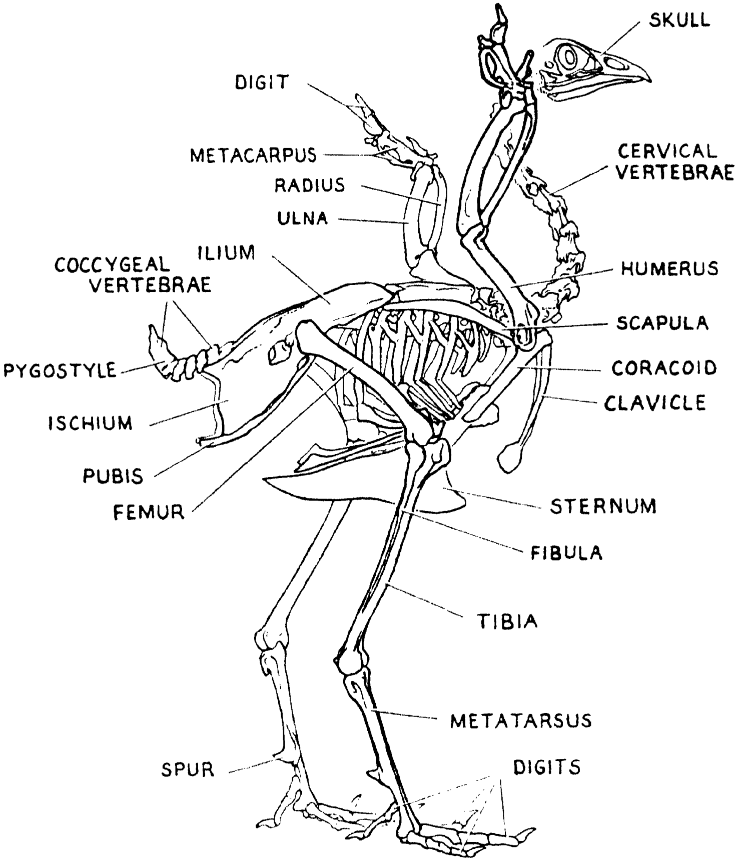


FIG. 100.—SKELETON OF FOWL.

The mineralised substances of compact bone are mainly tricalcium phosphate and calcium carbonate together with some magnesium salts. These are laid down in concentric plates or lamellæ around narrow channels called *Haversian canals* which tend to run along the length of the bone. The Haversian canals carry the blood supply and nerves through the bone. The bone cells (osteocytes) lie in small cavities called lacunæ between the lamellæ. The hollow central part of the bone shaft is filled with a yellow fatty material called yellow marrow.

Spongy bone is made up of numerous slender rods of osseous tissue called traberculæ which interlace to give a sponge-like structure. The spaces between the traberculæ are filled with red marrow which is responsible for the manufacture of red blood cells. Spongy bone with its associated red marrow is found, not only in the ends of the long bones, but also in the ribs, vertebræ and skull.

DENTITION

A study of the teeth is of special interest as variations in the number and condition of the teeth are commonly used to make approximate estimates of age. The teeth are hard structures set firmly in spaces in the jaw-bones and are used both in the intake of food and in its subsequent mastication ; they may also serve as weapons. Domestic animals have two sets of teeth during their life-time. At birth, or soon after, the young animal has a set of temporary teeth (often called " milk teeth "), but these are gradually replaced during growth by a set of permanent teeth.

Teeth can be classified into three groups :

1. Incisor teeth situated at the front of the mouth and used for seizing food.
2. Canine or eye teeth (of special importance to carnivorous animals) used for tearing and cutting food.
3. Cheek teeth which include the premolar and molar teeth. The premolars are situated in front of the molars and the molars are only represented in the permanent teeth. Both types are used in the grinding and mastication of food before swallowing.

Dental Formula. The dentition of an animal can be conveniently expressed as a dental formula, e.g. for the dog :

$$\text{Incisors } \frac{3-3}{3-3} \quad \text{Canines } \frac{1-1}{1-1} \quad \text{Premolars } \frac{4-4}{4-4} \quad \text{Molars } \frac{2-2}{3-3}$$

This indicates that there are three incisors on each side of the mouth in both the upper and lower jaws, and so on.

Dentition of the Ox. The dental formula of the ox is as follows :

$$\text{Incisors } \frac{0-0}{4-4} \quad \text{Canines } \frac{0-0}{0-0} \quad \text{Premolars } \frac{3-3}{3-3} \quad \text{Molars } \frac{3-3}{3-3}$$

The molars and premolars bear crescentic ridges which are characteristic of the ruminant. There are no incisors or canines in the upper jaw, these being replaced by a cartilaginous dental pad against which the incisors bite. In grazing the ox does not sever grass from the pasture with its teeth but harvests it with a long prehensile tongue. The permanent incisors are very much larger than the " milk teeth " and are known as " broad teeth ". Animals slaughtered when young may have no " broad teeth ".

The approximate arrangement of the teeth at different ages is:

Up to one month—temporary incisors up.
Eighteen months—central incisors up (two " broad teeth ").
Two and a half years—central and middle incisors up (four " broad teeth ").
Two and three quarter years—all incisors up (six " broad teeth ").
Three and a half years—canines up (eight " broad teeth ").

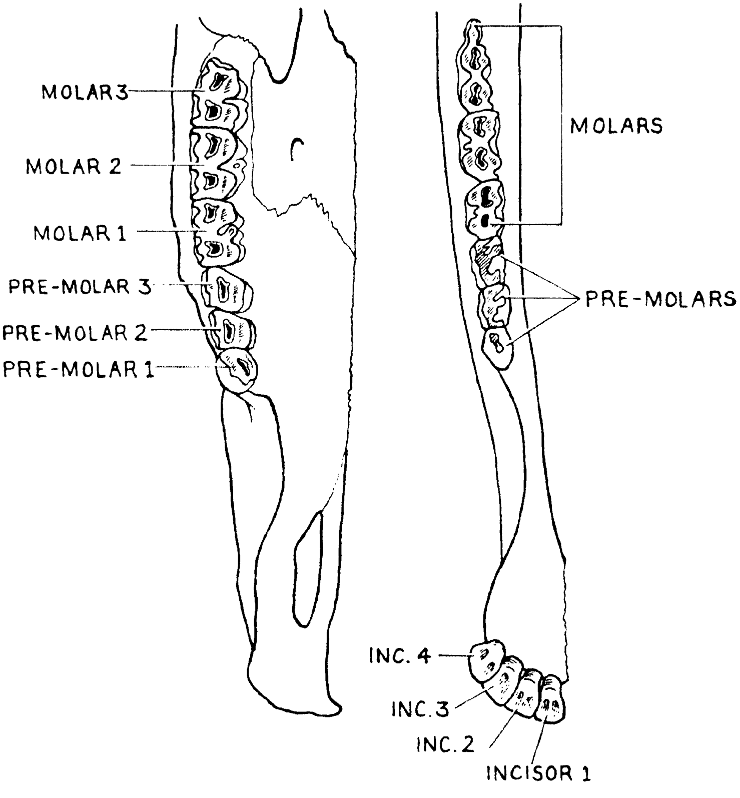


FIG. 101.—DENTITION OF OX.

Dentition of the Sheep. The sheep has the same dental formula as the ox. Its method of grazing is somewhat different because grass is actually severed from the pasture by the teeth. This process is assisted by a " split " lower lip which enables the sheep to graze much closer to the ground than the cow.

The approximate arrangement of the teeth at different ages is:

Birth to one month—temporary incisors up.
12 to 18 months—two central permanent incisors.
18 to 24 months—two middle permanent incisors.
30 to 36 months—two lateral permanent incisors.
3 to 4 years—two corner incisors or canines (eight " broad teeth " or a " full mouth ").

By the time the sheep is six to eight years old the permanent teeth develop gaps between them and begin to fall out ; the sheep is then referred to as being " broken-mouthed ". As sheep are often rejected from the flock when they become broken-mouthed, it is important to investigate the factors causing wear in sheeps' teeth.

Dentition of the Pig. The pig has the following dental formula :

$$\text{Incisors } \frac{3-3}{3-3} \quad \text{Canines } \frac{1-1}{1-1} \quad \text{Premolars } \frac{4-4}{4-4} \quad \text{Molars } \frac{3-3}{3-3}$$

The pig differs from ruminants in having incisors and canines present in the upper jaw. The canines are enlarged to form the tusks, which are exceptionally large in the boar. The molars and premolars are provided with knobs or bosses in place of the crescentic ridges of the ruminant. The order of development of the teeth is as follows :

Birth—two temporary teeth on each side of the jaw (incisors and canines).
Three months—full mouth of temporary teeth.
Nine months—two permanent teeth on each side (incisors and canines but the latter only just above the gums).
Thirteen months—a pair of permanent central incisors in each jaw.
Eighteen months—a pair of lateral incisors in each jaw (full mouth).

THE MUSCULAR SYSTEM

The most important property of muscle is its power of contraction which enables it to effect movement. Thus muscles are found at any point in the body where movement is required including not only the muscles of the limbs, trunk and neck, but also those of the heart, the blood vessels, the digestive organs and many other parts of the body.

There are different types of muscle which can be classified in various ways. For example, microscopic examination of muscle shows that it is composed of thread-like fibres. If the fibres exhibit cross striations or stripes the muscle is known as striated muscle. If, however, there are no cross striations, the muscle is called smooth or unstriated muscle.

Muscles can also be classified on the basis of the way they function. If a muscle is under voluntary control, e.g. the muscles of the limbs, it is called a *voluntary* muscle. If the action of a muscle is outside the control of the will, e.g. movements of the muscles of the digestive system, it is called an *involuntary* muscle. Generally, striated muscle is voluntary and smooth muscle is involuntary. The muscle of the heart is exceptional as it is partially striated but involuntary, and for this reason is usually classified separately as *cardiac muscle.*

A further name is commonly given to striated muscle ; as it is almost invariably attached to the skeleton it is known as skeletal muscle.

Skeletal Muscle. This is responsible for the movement of the limbs, trunk and head. It is adapted to respond rapidly to a stimulus and to work hard for limited periods. Thus violent exercise soon leads to muscular fatigue and a rest period is required.

Muscles are attached to bones, and movement is brought about in the following manner: one of the bones to which a muscle is attached is held in a relatively fixed position by the action of other muscles and then the muscle which makes the movement (the prime mover) has a fixed point against which to contract. This point of attachment of a muscle to a bone is called its origin. The point of attachment of the other end of a muscle is known as its insertion. At its origin the muscle is attached more or less directly on to the bone, but at its insertion blends into a tough fibrous tendon which actually unites with the bone.

Individual muscles can be classified according to the types of movement which they cause. For example, muscles which bend a limb are called flexors, and those which straighten a limb, extensors.

An interesting point about the structure of skeletal muscle is that the number of fibres in a muscle does not change after birth. Therefore increases of muscular size during growth must be due to an increase in the size of individual fibres and the incorporation of non-muscular material, e.g. fat into the muscle.

To the farmer, muscles are important not only because they effect movement, but also because they form the most important final product of the meat animal—the lean meat. The quality of meat is largely determined by the lean meat. The muscle must be tender, not too strong in taste and of a bright pinky-red colour. This type of meat can be produced from the well-fed, fast growing animal slaughtered at a young age.

Smooth Muscle. This type of muscle responds slowly to a stimulus but is capable of working for long periods at a slow steady pace, without tiring. It is found in the walls of the intestines and blood vessels and in all the organs of the body cavity where sustained movement is required. The activity of this type of muscle is outside the control of the will.

Microscopic examination shows that smooth muscle fibres are shorter than those of skeletal muscle and are rather spindle-shaped. They do not exhibit cross striations. Also, unlike skeletal muscle fibres, the fibres of smooth muscle can divide by mitosis to produce more fibres.

Cardiac Muscle. The heart has very special needs, to which cardiac muscle is adapted. Like smooth muscle it can work steadily day after day without tiring but, like skeletal muscle, it is capable of periods of intense activity when the demands of the heart are great.

THE NERVOUS SYSTEM

In a higher animal with its complex structure there must be some means of co-ordinating the activities of the body to avoid any conflict of purpose. This is provided by the nervous system.

The basic structural unit of the nervous system is the nerve cell or *neuron* (Fig. 102). The body of the nerve cell has several spidery processes called *dendrites* and a single, long conductile thread called the *axon.* These processes of the nerve cell can be referred to as nerve fibres. Nerve cells are linked together by the axon of one cell making contact (but not structural union) with the dendrite of another cell.

Contacts of this type (synapses) can be found in the central nervous system which is described below.

Some nerve fibres transmit messages from the extremities of the body arising from touch, sound, light, heat, etc., and give rise to the sensations ; they have a sensory function. Other fibres carry messages to the muscles causing movement and these are called motor nerves. Usually the nerve fibres are bound together in bundles to form what are generally called nerves.

The nervous system can be divided up into two parts, made up of the central nervous system and the peripheral nervous system.

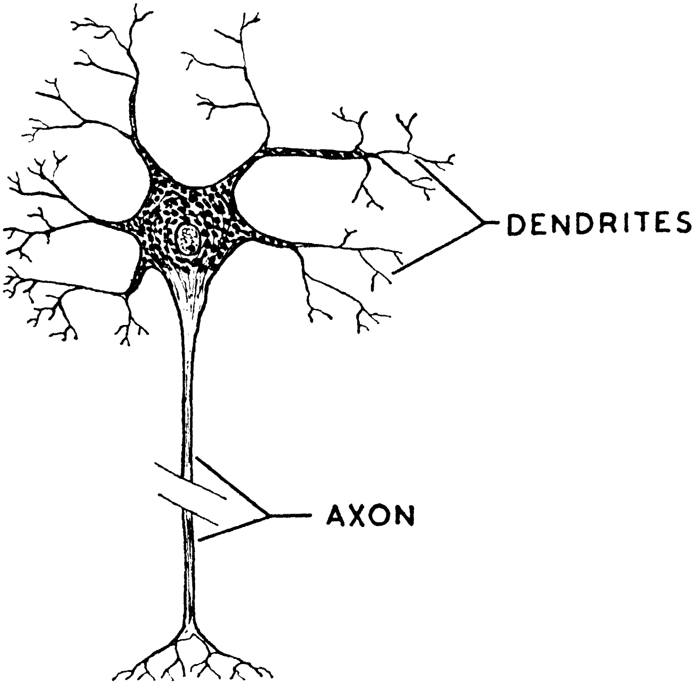


FIG. 102.—A NERVE CELL OR NEURON.

The Central Nervous System. This includes the brain and the spinal cord. The brain is the headquarters of the nervous system and is well protected against damage by the bony structure of the skull. It receives messages and impressions from all parts of the body, and gives rapid and decisive orders for appropriate action by the body. The importance of the brain is so great that even minor brain-injuries may seriously affect the ability of the animal to co-ordinate its activities.

The spinal cord arises from the rear part of the brain and runs the entire length of the vertebral column lying in the well protected neural canal.

Both the brain and the spinal cord are composed of white and grey matter. The reason for this colour differentiation is that the white matter is composed only of nerve fibres, whereas the grey matter contains the cell bodies of the neurons and their shorter processes.

The Peripheral Nervous System. At the point where the spinal cord and brain join, there arises a series of nerves which supply the head and certain other parts of the body. These are known as cranial nerves as they originate from within the cranium. The spinal cord also gives rise to nerves at intervals along its length and these pass to all parts of the trunk and limbs. Injuries to the spinal cord generally result in a paralysis of most parts of the body posterior to the point of injury.

These nerves outside the central nervous system but arising from it constitute the peripheral nervous system.

The Autonomic Nervous System. Some responses to nervous activity, e.g. the movement of a limb, are under the control of the will. Some functions, e.g. movements of smooth muscle, takes place automatically without effects on the conscious mind. These activities are controlled by a special division of the nervous system called the involuntary or autonomic nervous system.

FATTY TISSUE

Fat is a structural material of all cells and, as such, fat is essential to the animal. Fatty tissue is also laid down in special fat depots, e.g. beneath the skin and in the body cavity, and these depots represent a store of reserve food materials upon which the animal can draw in times of food shortage. When the animal is short of food the fat depots are the first of the body tissues to be depleted as a source of energy.

Fatty or adipose tissue consists of a mass of cells so laden with fat that the nucleus is pushed to one side of the cell. The most important fat depots occur in the abdominal cavity associated with the kidneys and digestive organs, beneath the skin (sub-cutaneous fat), between the muscles (inter-muscular fat) and within the muscles (intra-muscular or " marbling " fat).

THE DIGESTIVE SYSTEM

The digestive system is concerned with the conversion of ingested food into portions which can be absorbed into the blood stream, by which nutrients are transported around the body. The principal chemical constituents of the food are carbohydrates, proteins and fats to which must be added certain essential minerals, vitamins and water. These various substances are considered in Chapter XVIII. Although these essential food substances are required by all animals the nature of the diet from which they are obtained differs markedly from species to species. The digestive systems of different species have become adapted to deal with the different types of food eaten. The digestive systems of farm animals can be divided into three groups :

1. The simple stomached or monogastric type, e.g. the pig.
2. The ruminant type, e.g. cattle and sheep.
3. The avian type, e.g. the domestic hen.

The Monogastric Digestive System. The digestive tract consists essentially of a long coiled tube, the alimentary canal or gut, which traverses the entire length of the body. The main regions of the alimentary canal are the mouth, pharynx, œsophagus or gullet, stomach, small intestine and large intestine (Fig. 103).

In the mouth, food is ground by the molar teeth, and as this process continues the food is moistened by the secretion of saliva from the salivary glands of the mouth. When chewing is complete small boluses of food are swallowed, passing through the pharynx and into a long distensible tube, the *œsophagus*. The œsophagus extends through the thoracic cavity and passes through the diaphragm (a musculo-membranous partition separating the thorax and abdominal cavity) into the abdominal cavity. In the abdominal cavity the gut enlarges to form a sac, the stomach. The junction between the œsophagus and the stomach is guarded by a muscular valve, the *cardiac sphincter*, and the exit from the stomach is guarded by a similar valve called the *pyloric sphincter*.

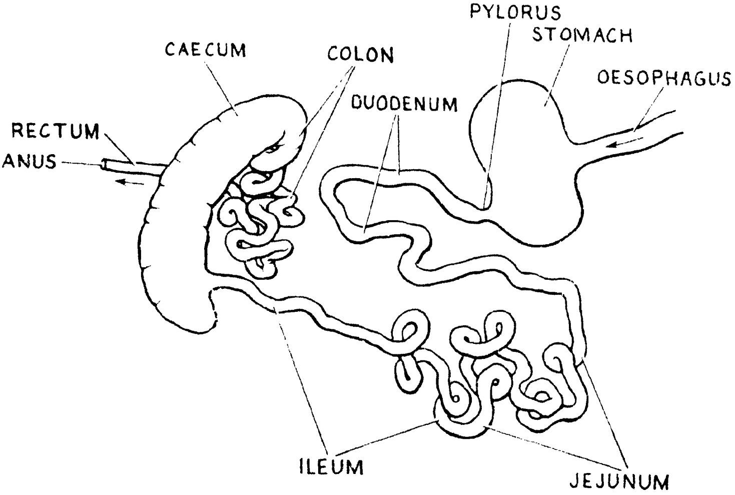


FIG. 103.—DIGESTIVE TRACT OF PIG (DIAGRAMMATIC).

From the stomach leads off an extremely long coiled tube with thin walls called the *small intestine*. Near the stomach the small intestine forms a loop called the *duodenum*, with which is associated a secretory organ known as the *pancreas*. From the duodenum onwards the small intestine is attached to the dorsal wall of the abdomen by a membrane called the *mesentery*, which carries blood vessels and nerves to the intestinal wall.

The small intestine leads into a much wider tube, the large intestine, which can be divided into three regions, (*a*) a blind sac, the *cæcum*, (*b*) the *colon* and (*c*) leading from the colon, the *rectum* which opens externally by the anus.

The Ruminant Digestive System. Cattle, sheep and goats eat large quantities of bulky foods such as grass, and the digestive tract is modified for the storage and digestion of this large bulk. It is popularly believed that the ruminant has four stomachs, but in fact there is only one true stomach. The other three stomach-like compartments are really enlargements of the posterior end of the œsophagus (Fig. 104). The names of the four compartments are, (*a*) the *rumen* or paunch, (*b*) the *reticulum* or honeycomb stomach, (*c*) the *omasum* or book and (*d*) the *abomasum*, reed or rennet stomach which is the true stomach.

In the newborn calf or lamb the rumen, reticulum and omasum are relatively poorly developed and are non-functional. At this stage, which can be called the pre-ruminant phase, the young animal is incapable of using bulky foods in its diet. At two to three weeks of age when solid foods begin to be eaten, these parts of the stomach complex (especially the rumen) develop rapidly and become functionally active.

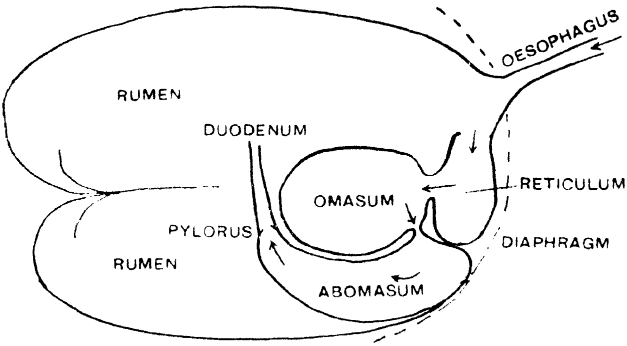


FIG. 104.—THE RUMINANT STOMACH.

The capacity of the rumen in adult cattle is enormous, amounting to some 50 to 60 gallons, and the rumen therefore fills the greater part of the abdominal cavity. The remaining compartments are all much smaller. The reticulum has an internal lining, the structure of which resembles a honeycomb ; it is in this compartment that heavy objects such as pebbles eaten accidentally tend to accumulate. Internally the omasum has many leaves of tissue resembling a book, and is an organ concerned with the absorption of water. The abomasum is a relatively long tubular sac and is the only part of the stomach complex which secretes digestive juices (see page 505). The abomasum is sometimes called the rennet stomach.

The large quantities of vegetable material eaten by the ruminant are stored in the rumen. Subsequently this material is regurgitated into the mouth, where it is mixed with the copious secretion of the salivary glands and ground into fine particles by the molar teeth. This activity is known as *cudding* or *rumination*. When the material is finely ground it is swallowed, water is absorbed by the omasum and the fine particles of food pass into the abomasum. From this point the processes of digestion are very similar to those of the monogastric animal.

It would be wrong to assume that the rumen is merely a place where food is stored, for active digestion of some food products takes place in this organ. This is possible because the rumen contains an enormous population of micro-organisms including bacteria and protozoa. These have several important functions. They are responsible for the digestion of the fibrous cellulose found in vegetable foods which cannot be utilised by the normal digestive processes : the cellulose is broken down by bacterial activity to produce short-chain fatty acids (acetic, butyric and propionic acids) which are absorbed through the lining of the rumen, pass into the blood stream and are used as a source of energy by the animal.

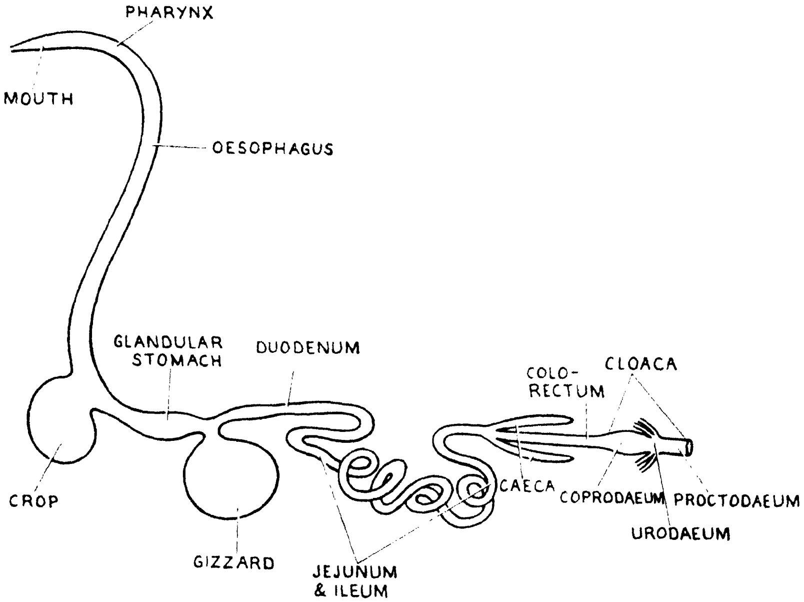


FIG. 105.—DIGESTIVE SYSTEM OF FOWL (DIAGRAMMATIC).

A second important function of the rumen micro-organisms is that they take plant proteins and certain other nitrogenous compounds and build them up into microbial protein. When the micro-organisms die, they pass into the abomasum and along the digestive tract where they are digested, thus forming a valuable protein food. Not the least important activity of the micro-organisms is that they have the power to synthesise certain vitamins essential to the animal, including many of the B vitamins and vitamin C. The rumen provides an example of a relationship between a higher animal and micro-organisms which operates to give mutual benefits.

An important result of microbial activity is that large volumes of gas are produced in the rumen ; normally this gas is removed by belching or eructation, which is a normal phenomenon in the healthy ruminant. If the belching mechanism is inhibited gas accumulates and causes distention of the rumen, giving rise to a condition known as *bloat* or *hoven* (see p. 711).

The horse, which also eats large quantities of vegetable food, has a rather different arrangement of the digestive organs. The horse is a monogastric animal, but microbial digestion of cellulose takes place in the large intestine which is much enlarged in this species. The process appears to be less efficient than in the ruminant.

The Avian Digestive System. The general arrangement of the digestive organs of the hen is illustrated in Fig. 105. The hen has no teeth and food is swallowed without chewing. At the entrance to the thorax the œsophagus enlarges to form a sac called the *crop*, where food is stored. Food in the crop is mixed with saliva, and then passes into the relatively small glandular stomach which is called the *proventriculus*. From the proventriculus food passes into another larger sac, the *gizzard*, which has thick muscular walls. The gizzard has a lining of hard, horny tissue and contains grit and, with the movements of the muscular wall, these grind the food.

The structure and functions of the small intestine are essentially similar to those of other species, but the large intestine shows some structural differences. Instead of a single cæcum there is a pair of cæca, and a relatively short colon opens to the exterior via the *cloaca*. The cloaca has a dual function, being also the opening of the uro-genital system.

THE PROCESSES OF DIGESTION

The proteins, fats and carbohydrates contained in foodstuffs are composed of complex molecules : the function of digestion is to break these down into smaller chemical units which can be absorbed through the intestinal wall and so pass into the bloodstream. The rate at which these chemical reactions proceed is normally slow. In various parts of the digestive system there are glands which produce secretions known as the *digestive juices* ; these juices contain ferments or enzymes which have the power to accelerate the rate at which specific chemical reactions occur. As the food passes through the digestive system different digestive juices are progressively secreted on to the food.

The passage of food through the alimentary canal is accomplished because the walls of the digestive organs contain smooth muscle fibres. Under the control of the autonomic nervous system these muscles contract rhythmically and gradually force food along the alimentary canal, continually churning the food and mixing it with the digestive juices as they do so. This process is called *peristalsis*. Occasionally food may be moved in the opposite direction, and this is referred to as anti-peristalsis.

The Digestive Juices. It has already been stated that the digestive juices contain enzymes which bring about chemical changes in food. The most important of the juices are :

Saliva. This is produced in the salivary glands which are situated at the base and sides of the mouth. Saliva has the important function of lubricating the food during mastication and so rendering it easy to swallow. It also contains an enzyme, *ptyalin*, which aids the conversion of starch into simple sugars. Enzymes which act on starch in this way are called amylases. There is no evidence of the presence of ptyalin in the saliva of cattle, sheep, horses or goats.

The secretion of saliva is under neural control and frequently the sight or thought of food induces a flow of saliva into the mouth.

The Gastric Juice. The gastric or stomach juice contains (*a*) *rennin* which curdles milk, (*b*) *pepsin* which converts insoluble proteins into more soluble peptones, (*c*) *lipase* which has a weak action on very finely divided (emulsified) fat droplets such as those of cream, and (*d*) hydrochloric acid which provides the acid conditions under which the enzymes of the gastric juice work best.

Rennin coagulates milk, producing a flocculent mass called a curd, and a clear fluid called whey. This reaction has been used from ancient times in the manufacture of cheese, employing rennin extracted from the stomach of the calf. Because of its action on proteins, pepsin is known as a proteolytic or protein-splitting enzyme.

As digestion proceeds the acidic contents of the stomach are gradually released into the small intestine where they are subjected to the action of the bile, the pancreatic juice and the intestinal juice.

Bile. The bile is produced in the liver, and is then stored in a small pear-shaped body called the gall-bladder, which is attached to the liver. There is no gall bladder in the horse, and it may be absent from individuals of other species without adverse effects. From the gall bladder the bile flows along the bile duct, which enters the small intestine in the region of the duodenum.

The bile itself contains no digestive enzymes ; it is largely composed of alkaline salts which have two important functions. Firstly, the bile salts cause fats to emulsify, i.e. to be reduced to minute droplets, in which state they can be more readily digested. Secondly, bile neutralises the acidity of material passing from the stomach and provides the slightly alkaline conditions in the small intestine necessary for the efficient activity of enzymes secreted by the pancreas and small intestine.

The Pancreatic Juice. This is also an alkaline secretion and includes three important enzymes, (*a*) *trypsin* which is proteolytic, (*b*) *amylopsin* which is an amylase, and (*c*) *steapsin* which is lipolytic or fat-splitting.

Trypsin acts upon proteins and peptones, breaking them down into smaller units called peptides. Amylopsin continues the breakdown of starch into sugars and steapsin splits fats into their component fatty acids and glycerol.

The Intestinal Juice. An alternative name for the intestinal juice is the *succus entericus*. It contains (*a*) peptidases which effect the final breakdown of peptides into amino acids which are the basic structural units of proteins, (*b*) Sucrase, maltase and lactase which act upon the sugars sucrose, maltose and lactose, breaking them down into simple sugars (largely glucose), and (*c*) lipase, a lipolytic enzyme which continues the digestion of fat.

The lower parts of the digestive tract, the cæcum, colon and rectum, secrete no digestive juices.

The Absorption of Digested Materials. Digestion produces simple sugars, amino acids, fatty acids and glycerol which can be absorbed into the circulatory system. The indigestible residue is voided in the fæces.

Almost the whole absorption of food products takes place in the small intestine, though some absorption of water and minerals (and possibly glucose) takes place in the stomach ; the absorption of water takes place in the large intestine and, in the ruminant, absorption of fatty acids occurs in the rumen. The small intestine is specially adapted for the absorption of food. This is due to the formation of millions of minute finger-like projections or *villi* (Fig. 106) which develop on the internal surface of the small intestine and so increase the absorptive area. Each villus is covered by a layer of delicate epithelial cells surrounding a network of blood capillaries which are fed by a small artery and drained by a small vein. Within this network is a lymph capillary or lacteal (see p. 512) opening into a small lymph vessel which passes away from the villus.

The epithelial covering of the villus allows the passage of smaller molecules such as glucose which enter the blood capillary and are thence transported to all parts of the body. Absorption is not merely a passive process ; the epithelial cells play an active part in absorption and may exercise a selective effect in absorbing one product before another.

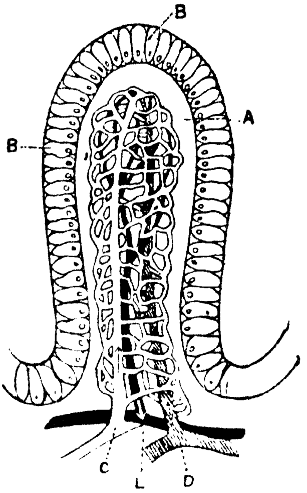


FIG. 106.—A VILLUS OF THE SMALL INTESTINE.

A, body of the villus. B, external covering of epithelium cells. C, the small artery entering the villus and breaking up into capillaries, which reunite to form—D, the small vein which leaves the villus. L, the lacteal radicle which occupies the middle of the villus.

The absorption of fat is rather different from that of other food products. It has been suggested that fat is broken down by lipolytic enzymes into fatty acids and glycerol. This is partly true, but a large proportion of fat is not subjected to the activity of lipolytic enzymes, and remains in the small intestine in emulsified form. This emulsified fat can pass directly through the epithelial cells into the villus. Fat is not transported by the blood vessels but enters the lacteal and is transported by the lymphatic system.

THE CIRCULATORY SYSTEM

The circulatory system provides a means of internal transport in the body. Essentially it consists of a system of tubes through which flow the blood and lymph which act as media for exchange. The blood system which carries the blood, and the lymphatic system which carries the lymph, are best considered separately.

The Blood System. This consists of a closed system of tubes through which flows the blood.

The Blood. Blood is composed of a fluid medium, the *plasma,* in which are carried innumerable cells or *corpuscles.* There are two types of corpuscles, red and white.

The red corpuscles are by far the more numerous, and each consists of a biconcave disc ; unlike most cells they have no nucleus. Individually the cells are yellowish-red in colour but, in a mass, give the blood its characteristic red colour. An important function of the blood is to transport oxygen to the tissues, and this is a property of the red corpuscles. The colour of the red corpuscles is due to a substance called *hæmoglobin* which has a remarkable ability to absorb oxygen. This takes place in the lungs, where oxygen forms a loose compound with hæmoglobin, called oxyhæmoglobin. In this state the blood is said to be oxygenated and has a bright scarlet colour. Blood passing through the tissues rapidly gives up its oxygen to the tissues, and the hæmoglobin is now known as reduced hæmoglobin. In this state the blood is said to be deoxygenated and has a dark purplish-red colour. Carbon dioxide, produced as a waste product of tissue activity, is removed in blood passing away from the tissues, part being attached to the hæmoglobin and part being carried in the plasma.

The white cells, or *leucocytes,* are larger and less numerous than the red corpuscles and have nuclei. These cells constitute an important defence mechanism of the body against invading micro-organisms. Leucocytes are capable of passing through the thin walls of the smallest blood vessels and wander through the tissues, tending to congregate in sites of bacterial infection. Here they engulf and digest pathogenic bacteria, so protecting the body from disease. The pus which exudes from a festering wound is largely composed of white cells.

It is important that, should a blood vessel be damaged, all the blood does not leak out of the blood system. In fact this does not occur (unless the damage is extensive) because the blood has the power to form a jelly-like clot. This clot acts as a block to further blood and the bleeding ceases.

The blood system consists of the heart, the arteries, the veins and the capillaries.

The Heart. The heart is a hollow muscular organ and is the central force pump of the blood system (Fig. 107). It is composed of two halves, the right and left halves, which are each divided into a thin-walled anterior compartment, the *auricle,* and a thick-walled posterior compartment, the *ventricle.* The heart is enveloped in a delicate membrane called the *pericardium* and has a lining membrane called the *endocardium.* Between the auricle and ventricle of each side is a communicating passage guarded by a system of valves. The exits from the ventricles are also guarded by a system of valves. These valves are so arranged that blood can pass from the auricles to the ventricles and from the ventricles outwards, but not in the opposite direction. There is no direct communication between the two halves of the heart.

The Arteries, Capillaries and Veins. The arteries carry blood from the heart towards the tissues, and the two largest arteries are the *aorta*, which is the sole outlet of blood from the left ventricle, and the *pulmonary artery*, which receives the contents of the right ventricle. Traced outwards from the heart, the arteries branch and subdivide like the branches of a tree, becoming progressively smaller until, in the tissues, they give rise to very small *arterioles*. The walls of the arteries and arterioles are well supplied with bands of smooth muscle innervated by the autonomic nervous system. Contraction and relaxation of the walls of the arterioles alters the internal diameter of these vessels and so regulates the amount of blood passing to any part of the body.

In the tissues, each arteriole breaks up into an extremely fine network of narrow tubes, the *capillaries*, which are just large enough to permit the passage of blood corpuscles. The wall of each capillary tube is composed of a delicate membrane only one cell thick. This wall holds the blood in the capillaries but allows some fluids, food products and oxygen to pass into the tissues, and waste products of tissue activity to pass from the tissues into the bloodstream. Thus it is in this region that the essential exchange of products between the blood and the tissues takes place. The walls of blood vessels larger than the capillaries are impervious to both gases and fluids.

The capillary network gradually re-forms into larger tubes through which blood begins its journey back towards the heart. The small vessels collecting blood from the capillaries can be called venules and these become confluent into larger veins which ultimately discharge their contents into the auricles of the heart. The walls of the veins are much thinner and less muscular than those of the arteries.

Circulation of Blood. The general lay-out of the blood system is illustrated diagrammatically in Fig. 107. Contraction of the left ventricle drives scarlet, oxygenated, blood into the aorta. The aorta sends branches to the head and fore-limbs, and then passes in a posterior direction, lying beneath the vertebral column. From this part of the aorta, branches supply blood to the liver, kidneys, digestive system, hind limbs, etc.

Blood in the aorta is under pressure, but as blood passes into the smaller arteries pressure falls, and in the arterioles and capillaries blood pressure is low. This fall in pressure is essential because otherwise the thin-walled capillaries would burst.

Blood leaving the capillaries is returned to the auricles of the heart through the venous system. Blood pressure in the veins is even lower than in the capillaries, and it has been noted that the veins are only weakly muscularised. How then does blood return to the heart? This is due to several factors, the most important being (*a*) the left ventricle is continually pumping blood into the arteries, thus forcing blood through the capillaries and into the venous system, (*b*) the thorax is always at a slightly negative pressure (see p. 513) which causes blood to be drawn towards the heart by suction, (*c*) muscular contraction presses against the veins and helps to force blood along them—animals may stretch after a period of sleep to aid this effect,

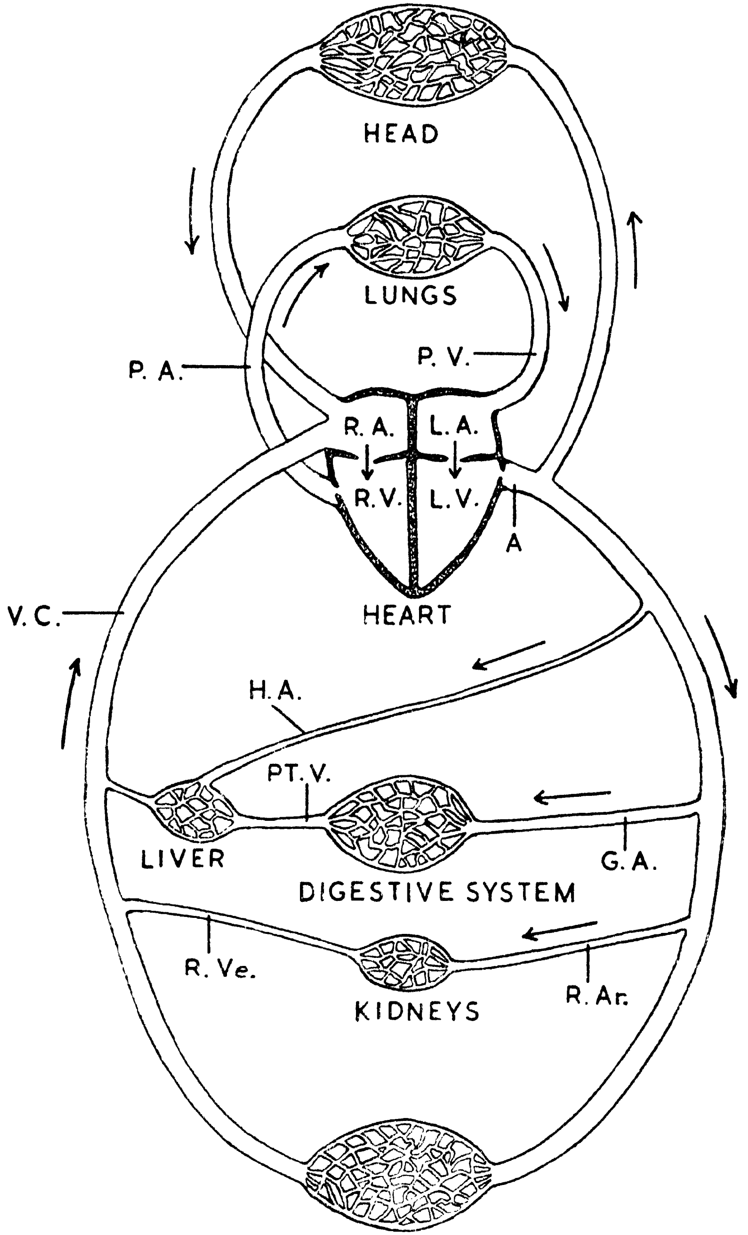


FIG. 107.—DIAGRAM OF THE CIRCULATION OF BLOOD.

R.A., right auricle ; R.V., right ventricle ; L.A., left auricle ; L.V., left ventricle ; P.A. pulmonary artery ; P.V., pulmonary vein ; A., aorta ; H.A. hepatic artery ; G.A., artery supplying intestines : R.Ar., renal artery ; R.Ve., renal vein ; PT.V., portal vein ; V.C., vena cava.

and (*d*) veins are provided with flap-like valves which allow blood to pass towards the heart but not in the reverse direction.

Dark, venous blood enters the right auricle of the heart, but, before being passed to the left ventricle to start a further journey round the body, it must be oxygenated. This is achieved through a special loop of the circulatory system, the pulmonary circulation, which carries blood to the lungs.

Venous blood in the right auricle is forced into the right ventricle by auricular contraction. Then contraction of the right ventricle forces blood into the pulmonary artery which passes to the lungs. In the lungs the capillaries line the air spaces where carbon dioxide is released from the blood and oxygen is taken up from inhaled air. Oxygenated scarlet blood is returned to the heart by the pulmonary vein, entering the left auricle. Contraction of the left auricle forces blood into the left ventricle and the whole cycle of circulation is recommenced.

The pulmonary circulation gives rise to a unique situation in the animal ; it provides the only case where an artery (the pulmonary artery) carries dark deoxygenated blood and a vein (the pulmonary vein) carries scarlet oxygenated blood. In all other cases veins carry dark, and arteries scarlet, blood. The arrangement of the pulmonary circulation also explains why there are two separate sides of the heart ; the right side is concerned with collecting blood from the body and pumping it through the lungs, while the left side receives blood from the lungs and pumps it round the body.

The Pulse. The working of the heart is so co-ordinated that first the two ventricles contract and then relax as the auricles contract ; then the auricles relax as ventricular contraction occurs again. This cycle of operations is known as the beating of the heart. As the left ventricle contracts, the rush of blood being forced into the aorta causes throbbing of the larger arteries. This is known as the pulse and can be felt in places where an artery passes over the surface of a superficial bone, e.g. in the human wrist or on the underside of a cow's tail.

The pulse rate gives a measurement of the rate at which the heart is beating, and the normal number of pulsations per minute is 55 in the adult ox, 75 in the sheep and pig and 130 in the domestic fowl. These figures cannot be accepted rigidly because pulse rates are subject to wide variations, increasing with exercise or excitement and being at a minimum when the animal is at rest. Abnormally high pulse rates are generally indicative of a feverish condition.

The Spleen. The spleen is a purplish-red organ situated in the abdomen near the stomach, and it plays an important part in the circulation of blood. Internally the spleen contains many spaces or sinuses filled with blood and these act as a reservoir ; when the demand for blood increases the spleen contracts, releasing its blood into the blood system. The spleen also has the important function of destroying wornout red blood corpuscles, and is a site where certain leucocytes are manufactured.

The Lymphatic System. It has been mentioned that fluids, food products and oxygen pass out of the capillaries into the tissues ;

here the fluid material is known as the tissue fluid. When the exchange of materials between these fluids and the tissues is complete, part of the fluid passes back into the venous end of the capillaries, but the remainder is drained from the tissues into the lymphatic system. The fluid drains into small capillary vessels of this system called *lymphatics*. Lymphatics present in the villi of the small intestine are given the special name of *lacteals*. The lymphatics become confluent into larger lymph vessels which are similar in structure to the veins. These ultimately open into two main ducts (*a*) the thoracic duct lying beneath the vertebral column, which drains the greater part of the body, and (*b*) the right lymphatic duct, which drains some regions of the head, fore-limbs and thorax, and part of the liver. These two main ducts open into a large vein in the neck region and thus all the fluids are finally returned to the blood system.

Tissue fluids entering the lymphatic system become known as the *lymph*, which is almost identical in composition with the tissue fluids and, in addition, contains large numbers of leucocytes. Normally no red blood corpuscles are present in the lymph. The ability of leucocytes to engulf and destroy bacteria has already been mentioned and their defensive activity is aided by the formation of small round bodies called lymph-nodes at strategic points along the lymph vessels. These filter out bacteria from the lymph and hold them in a position where they can be more easily attacked and destroyed by leucocytes ; in this way many bacteria are prevented from entering the blood stream. The lymph-nodes are also a site for the manufacture of leucocytes.

Movement of lymph is caused by muscles pressing against the lymph vessels during muscular contraction. Valves situated in the lymph vessels (which are similar to those of veins) ensure that lymph flows in the correct direction.

THE RESPIRATORY SYSTEM

The vital exchange of oxygen between atmospheric air and the blood takes place in the lungs, and air is drawn into the lungs through a series of air passages. These air passages are the nasal cavities, pharynx, larynx, trachea or wind-pipe, bronchi, bronchioles and air sacs (Fig. 108).

From the nose or mouth air passes through the pharynx and larynx and then enters the trachea which extends from the larynx into the thorax. The *trachea* is composed of a series of resilient rings of cartilage which give it its characteristic appearance. In the thorax the trachea divides into two branches, the right and left *bronchi*. Each bronchus enters the corresponding lung where it divides and subdivides into smaller branches, the terminal twigs being known as *bronchioles*. These open into irregularly shaped air sacs which are lined by the blood capillaries of the pulmonary circulation. It is at this point that air is brought into close contact with the blood for the purpose of gaseous exchange.

The lungs themselves consist mainly of air spaces surrounded by blood vessels and a pale-coloured elastic tissue. The lungs are each invested in a double membrane called the *pleura*, which enable the lungs to glide smoothly over the internal surface of the thorax as the respiratory movements take place.

During the process of gaseous exchange carbon dioxide passes into the air sacs and oxygen is taken up by the blood, reduced hæmoglobin being converted to oxyhæmoglobin. At the same time air in the lungs becomes warm and takes up some water vapour ; this means that the lungs can play a part in the excretion of water and in the regulation of body temperature—points which will be discussed later. As a result of the gaseous exchange the air in the lungs becomes richer in carbon dioxide and water vapour, and poorer in oxygen than atmospheric air. Clearly, before any further exchange can take place, air must be expelled from the lungs and be replaced by fresh atmospheric air. This is accomplished by a series of breathing movements.

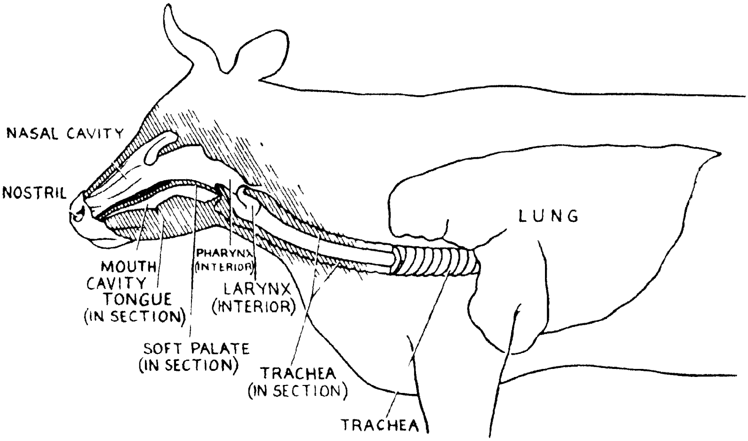


Fig. 108 Diagram of Respiratory System.

The Breathing Movements. The thorax is bounded by the ribs, the sternum, the backbone and the diaphragm, and is almost completely filled by the lungs and heart. The thorax is at a pressure slightly below that of the atmosphere due to the elasticity of the lungs.

The drawing of air into the lungs is known as inspiration or inhalation, and its expulsion as expiration or exhalation. Inspiration and expiration alternate rhythmically and occur at a rate of 26–30 per minute in the resting cow, 10–20 in the resting sheep or pig and 15–48 in the domestic fowl. Respiration rate is more rapid in young animals, after exercise and under conditions where the animal is hot or feverish.

Essentially the breathing movements are similar to the action of bellows where the nozzle of the bellows is equivalent to the trachea. At inspiration the volume of the thorax is increased, the lungs expand and air is drawn into the larger air tubes. This increase in the volume of the thorax is brought about by movements of the ribs and diaphragm. The intercostal muscles between the ribs contract and cause movements of the ribs and sternum which increase the volume of the thorax. At the same time the muscles of the diaphragm (a dome-shaped sheet of muscle which separates the thorax from the abdomen) contract ; as contraction occurs the dome becomes flattened and again the volume of the thorax is increased.

In expiration the intercostal muscles relax and the ribs and sternum return passively to their original position. At the same time the muscles of the diaphragm relax and it rises towards the thorax, this movement being aided by the negative pressure existing in the thorax.

In all these movements the elastic lungs play a purely passive role, expanding and drawing air into the lungs as the volume of the thorax increases during inspiration, and contracting as the volume of the thorax diminishes during expiration so that air is expelled from the lungs. It is important to note that the respiratory movements do not carry air directly into the air sacs ; the movement of gases to and from the air sacs through the bronchioles takes place purely by gaseous diffusion.

The breathing movements are normally under autonomic control, i.e. at the sub-conscious level, but can be controlled at the conscious level. Breathing is inhibited during swallowing to prevent food materials passing into the trachea. Coughing represents a rather violent modification of the breathing movements in response to irritation of the lungs.

THE EXCRETORY SYSTEM

The body possesses specialised excretory organs, the kidneys, but these are by no means the only organs concerned with the excretion of waste products. Some waste products may be excreted in the saliva, while others are excreted into the alimentary tract and pass out of the body with the fæces. It has been noted that carbon dioxide and some water vapour are eliminated from the lungs, and in this respect the lungs must be regarded as excretory organs. The liver also has an excretory function, for the bile, as well as aiding in the digestive processes, contains products of excretion. The skin, too, has an excretory function, for the perspiration carries excretory products. The kidneys have a most important function, as excretory organs, and are essential for the continuance of life.

The Kidneys. The two kidneys have a characteristic shape and are situated in the abdomen in a well-protected site beneath, and on either side of, the back-bone. Each kidney is embedded in a protective cushion of fat.

The excretory units of the kidney are microscopic nephrons (Fig. 109). Each *nephron* consists of two parts, a cup-shaped unit (Bowman's capsule), and leading from this capsule a long, looped tube, the *renal tubule.* The kidneys receive their blood supply from the renal artery and, in the kidneys, arterioles pass to the nephrons where they form a special capillary network, called the *glomerulus,* within Bowman's capsule. The vessel leaving the glomerulus passes on and forms a second capillary network laced round the renal tubule. Blood is drained from the kidneys by the renal vein.

Fluid materials leave the bloodstream from the glomerulus, pass into Bowman's capsule and then down the renal tubule. The fluid passing into Bowman's capsule contains not only waste products, but also substances (such as glucose) which are required by the body. These latter substances are selectively reabsorbed in the renal tubule, and pass back into the bloodstream through the capillary surrounding the tubule. The remaining fluid, the *urine*, passes on down the renal tubule. Gradually the tubules become confluent into larger tubes and urine leaves the kidney by a single tube, the *ureter*. In mammals the ureters from each kidney pass to a storage organ called the bladder, situated in the pelvic region of the abdomen. From the bladder a single tube, the *urethra*, conveys urine to the uro-genital organs, from which it passes to the exterior. In birds there is no bladder and the ureters open into the *cloaca*.

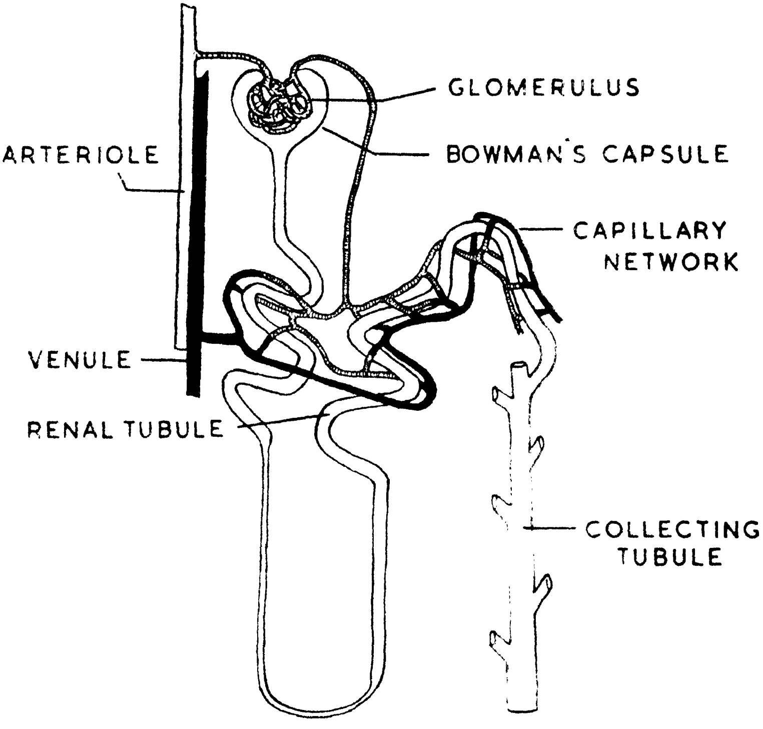


FIG. 109.—A KIDNEY UNIT OR NEPHRON (DIAGRAMMATIC).

Urine. The urine is composed largely of water, but contains several salts (including sodium chloride) and some nitrogenous compounds. The main nitrogenous compound produced by mammals is urea and by birds uric acid. Because of the presence of these materials, urine has a high fertilising value.

THE SKIN

The skin, in addition to serving as a protective covering for the body, is of considerable functional significance, being concerned both with excretion and with the regulation of body temperature.

Microscopic examination of the skin shows it to be composed of two layers, an upper *epidermis* and beneath this the *dermis*. The epidermis has mainly a protective function and is composed of several layers of cells, the outer layers being formed of dead scaly cells. The hairs also originate from the epidermis, though their roots are found in the dermis. The dermis is a thicker layer which contains the blood vessels and nerves of the skin : there is much adipose tissue in the lower layers of the dermis (the sub-cutaneous fat). From the dermis arise many coiled sweat glands, which pass through the epidermis and discharge their contents on to its surface. Also the roots of the hair follicles are found in the dermis, and each follicle has associated with it a sebaceous gland which secretes a lubricating fluid on to the hairs. The fowl has no sweat or sebaceous glands but the feathers are similar in origin to the hairs. Both hairs and feathers each have associated with them a small muscle which causes their erection ; the erection of hairs is most evident in frightened or enraged animals though it may also be observed when the weather is very cold.

Pigs have a rather sparse covering of hair, while cattle have a thick cover over most of the body. In both species the colour and pattern of hair distribution is distinctive of breed. In sheep the main cover is formed of a modified type of hair known as wool though true hairs are also present.

Temperature Control and Excretion. The normal average body temperature is 102° F. in the cow, 103° F. in the sheep, 102° F. in the pig and 107° F. in the fowl. Normally, body temperature is controlled within narrow limits and the control mechanism is associated with the skin. Heat is lost from the skin surface to the generally cooler air surrounding it. In temperature regulation the blood acts as a carrier of heat to a part of the body from which it can be lost. The blood vessels of the skin are under neural control and the magnitude of heat loss from the skin can be increased or decreased through variations in the quantity of blood passing through the skin. For example, if body temperature tends to rise (as on a hot day) the blood vessels of the skin dilate, more blood is brought from the interior of the body to the skin, and heat loss increases accordingly. Conversely, under cold conditions the blood vessels of the skin become constricted so that blood flow is reduced and heat is retained in the body.

If, under hot conditions, the increased blood flow to the skin fails to maintain temperature within normal limits, a nervous impulse from the brain stimulates the sweat glands to secrete sweat. As the sweat evaporates from the skin surface it has a cooling effect on the body. Under these conditions the animal is said to sweat or perspire.

Some excretory products are lost from the body in the sweat, but in the healthy animal the skin is relatively unimportant as an excretory organ.

Under extremely cold conditions body temperature may tend to fall in spite of constriction of the blood vessels ; if this occurs spasmodic muscular contractions are initiated and the animal is said to shiver. The heat produced as a by-product of this muscular activity helps to bring body temperature back to within normal limits.

There are, of course, limits within which normal body temperatures can be maintained. Small or moderate fluctuations can be quickly rectified but, under conditions of extreme heat or cold, the temperature-regulating mechanism may break down with serious consequences. The new-born animal is extremely sensitive to temperature changes and may quickly die under cold conditions.

THE ENDOCRINE SYSTEM

The way in which enzymes can accelerate the rate at which particular chemical reactions occur has already been described in relation to the digestive processes. Other substances produced in the body have the power to regulate whole body processes rather than single reactions ; these are known as *hormones* and are secreted by the glands of internal secretion or *endocrine glands*. These hormones are secreted into the bloodstream and are thus rapidly conveyed to the organ or organs upon which they exert their effect.

The most important endocrine glands are the thyroid glands, the parathyroid glands, the adrenal glands, the pancreas and the pituitary gland.

Thyroid Glands. The thyroids are a pair of glands situated in the neck on either side of the trachea. Their secretion, *thyroxine*, is a hormone which regulates the general level of activity of the body. If thyroxine secretion is inadequate the activities of the body become very sluggish and, conversely, if the rate of secretion is excessive the body becomes over-active with a rapid loss of weight and an excitable nervous condition develops.

In the region of the thyroid glands can be found two smaller glands called the parathyroids. They are concerned with the storage and utilisation of calcium and phosphorus : milk fever of dairy cows (see p. 709) is a symptom of temporary parathyroid inactivity.

Adrenal Glands. The adrenal glands are situated in the abdominal cavity, one being near each of the kidneys. Each gland consists of two distinct parts, an internal medulla and, enclosing this, the cortex. The adrenal medulla secretes *adrenalin* in times of excitement, fear or intense muscular activity. It causes the heart rate to increase and the arteries of the skin are constricted so that the blood flow to the skeletal muscles is increased. At the same time there is a rapid release of glucose from the liver which is conveyed to the muscles, where it is used as a fuel for muscular work. A further effect of adrenalin is to cause contraction of the smooth muscles attached to hairs or feathers, and this explains why they are elevated during fear or excitement. The adrenal cortex secretes many hormones, which are referred to collectively as corticoids. These have effects on a whole range of body functions and are intimately concerned with the control of water and salt levels in the body.

The Pancreas. The pancreas has been described already as an organ which elaborates digestive enzymes, but it also has an endocrine function. Its secretion, *insulin*, is concerned with the regulation of blood sugar levels ; insulin insufficiency results in high levels of sugar in the blood and the appearance of glucose in the urine. This condition is referred to as diabetes : human diabetics can lead normal healthy lives as long as they receive regular injections of insulin.

Pituitary Gland. One of the most important endocrine glands is the pituitary gland because many of its secretions regulate the activities of other endocrine glands. The pituitary gland is situated in a well-protected site in the floor of the skull and is divided into two main regions called the anterior and posterior lobes. The posterior lobe secretes *oxytocin*, a hormone which causes smooth muscle fibres to contract and which, amongst other phenomena, is responsible for milk " let down " (see p. 627). The anterior lobe produces six hormones, (*a*) growth hormone which stimulates growth (particularly of bone and muscle), (*b*) thyrotrophic hormone which stimulates the thyroid glands to secrete thyroxine, (*c*) adrenocorticotrophic hormone which stimulates the adrenal cortex to secrete corticoids, (*d*) and (*e*) two gonadotrophic hormones which control the activities of the gonads (the ovary and testis), and (*f*) prolactin which stimulates milk secretion.

The gonads may also be regarded as endocrine glands, but are described separately below.

REPRODUCTION IN MAMMALS

The Female Reproductive Organs. That part of the reproductive tract visible from the outside of the body is the *vulva* surrounding the uro-genital opening. Associated with the vulva is a small erectile organ which is analogous to the male penis and is called the *clitoris*. From the vulva leads a broad tube called the *vagina*, some inches along which is a narrow neck called the *cervix* which opens into the *uterus* beyond it. The main body of the uterus divides into two uterine horns which are suspended from the body wall by a ligament. Each uterine horn leads into a long narrow tube called the *oviduct*, which opens into a membranous funnel. This funnel is open to the body cavity but partly envelops the *ovary*, which is a small ovoid structure (Fig. 110).

Stimulation of the ovaries by gonadotrophic hormones results in the production of the female gametes, *ova* or eggs and the female sex hormone called *œstrogen*. The ova are produced in small spherical follicles which project slightly from the surface of the ovary. During formation of the ovum there is a meiotic or reduction division of the nucleus (see p. 463) so that the gamete is haploid. Each ovum is a microscopic spherical body consisting of a nucleus surrounded by a series of delicate cell membranes. Œstrogen is produced by the cells lining the ovarian follicle and is responsible for, (*a*) the female characteristics, (*b*) heat or œstrus (the period during which the female is receptive to the male), and (*c*) the development of the mammary gland or udder.

As the ovum develops with the follicle, the follicle itself increases in size and finally ruptures in the act of ovulation, or setting the ovum free. The ovum falls into the funnel at the head of the oviduct and passes into the oviduct where fertilisation occurs. After fertilisation the ovum passes into the right or left horn of the uterus to the wall of which it becomes attached and where development of the fœtus occurs.

After ovulation the cells lining the ovarian follicle proliferate rapidly and form a knob-like projection on the surface of the ovary known as the *corpus luteum.* This is an endocrine gland and secretes *progesterone,* a hormone which stimulates the uterus to nourish the developing fertilised ovum and which, like œstrogen, is concerned with the development of the mammary gland.

The Male Reproductive System. The essential male organs are two *testes* which lie in the *scrotum*, a sac outside the body cavity.

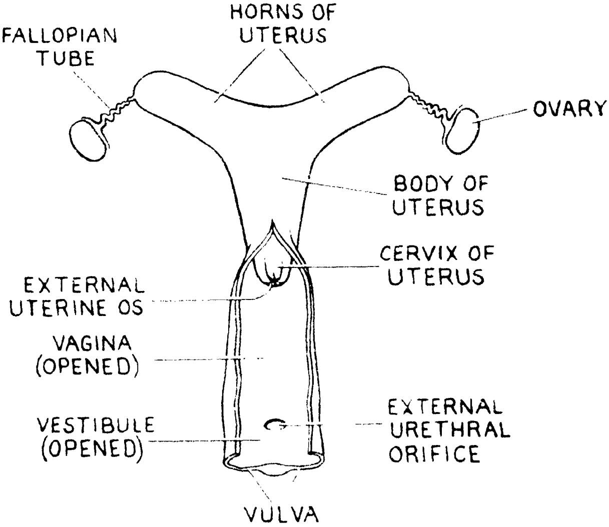


FIG. 110.—DIAGRAM OF FEMALE GENITALIA.

The reason for this apparently exposed position of the testes is that they function most efficiently at temperatures below those of the body cavity. Gonadotrophic hormones stimulate the testes to produce the male gametes or *spermatozoa* and the male sex hormone called *androgen.*

Androgen is responsible for the male characteristics and sexual desire. Castration (removal of the testes) inhibits the development of these characters and is commonly practised where animals are being reared for meat production, for it has a quietening effect on the animal and improves the quality of the meat produced.

Each minute spermatozoon has an ovoid head region, a short cylindrical body and a long thin tail which by whip-like movements is capable of causing movements of the spermatozoon. Like the ovum, each spermatozoon has a haploid nucleus. After production spermatozoa are stored in the *epididymis,* a tube situated within the scrotum. From the epididymis a duct leads back into the abdominal cavity, where it joins with the urethra in the region of the bladder. The urethra is therefore a common uro-genital duct and passes to the exterior through the *penis* (Fig. 111).

Fluids are secreted into the urethra from a number of accessory glands including the seminal vesicles, the prostate gland and Cowper's glands ; the mixture of these fluids and spermatozoa is known as *semen*, and each drop of semen may contain many thousands of spermatozoa.

The male copulatory organ or penis is formed of erectile tissue, and at copulation it becomes erect due to the accumulation of blood within this tissue. In copulation the penis is inserted into the female vagina, and neural stimuli cause contractions of the epididymis and vas deferens thus forcing semen out through the penis and into the upper end of the vagina ; this is called ejaculation. The quantity of semen produced at ejaculation shows considerable species variation, amounting to 1–2 c.c. in the ram, 5 c.c. in the bull and up to 500 c.c. in the boar. Once deposited in the vagina, spermatozoa are transported to the oviducts, partly due to movements of the spermatozoa themselves and partly by rhythmic contractions of the uterine wall.

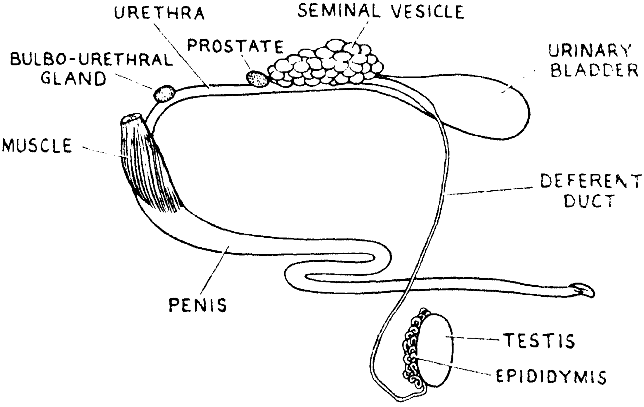


FIG. 111.—DIAGRAM OF MALE GENITALIA (BULL).

In fertilisation a single spermatozoon enters the ovum ; there is a fusion of nuclear material between the two cells, and the resulting fertilised ovum is the parent cell of the future offspring.

The Œstrous Cycle. The lives of both the ovum and spermatozoon are strictly limited, and for successful fertilisation it is therefore essential that mating should occur near the time of ovulation. This is ensured because, although the male will mate at almost any time, the female is only receptive to the male when she is in " heat ", or œstrus. The phenomenon of heat is due to the action of œstrogen produced by the ovarian follicle, and ovulation usually occurs towards or at the end of heat. This arrangement ensures that, after mating, spermatozoa will be present in the oviducts as ova pass from the ovaries.

The average duration of heat is eighteen hours in the cow, thirty-six hours in the ewe and two to three days in the sow : heat normally occurs at regular intervals. The interval between heats is known as the œstrous cycle. The period of sexual quiescence between heats corresponds to the time when the corpus luteum is actively secreting progesterone. As the activity of the corpus luteum declines, œstrogen is again secreted by the developing ovarian follicle and a further heat occurs.

In the non-pregnant cow and sow, heat occurs at intervals of about twenty-one days throughout the year.

The sheep, however, is a seasonal breeding species and in the ewes of most breeds breeding activity is confined to the autumn and winter months. During this period heat occurs at intervals of about sixteen days. In the spring and summer months the ewe is unreceptive to the ram, and this is known as the anœstrous period. Thus, although pigs and cattle can be mated to produce young at any season of the year, lambs are born over a fairly short period in late winter and spring.

If ova are fertilised after mating, the corpus luteum does not decline in activity as in the normal œstrous cycle, but continues to secrete progesterone ; no further œstrous cycles occur until after the young are born.

Pregnancy. After fertilisation the fertilised ovum passes into the uterus, which has been stimulated by progesterone to nurture the developing egg. As development proceeds, two distinct structures are formed within the uterus ; (*a*) the *placenta* or afterbirth, which becomes attached to the inner wall of the uterus ; its function is to bring the blood supply of the fœtus into close relation with that of the dam and so to act as an organ of fœtal nutrition, respiration and excretion, and (*b*) the *fœtus* or embryo, which is attached to the placenta by the navel cord. In the placenta the blood supplies of the fœtus and dam do not actually mingle, but an exchange of materials takes place between the capillaries of the two blood systems.

When fœtal development is complete, *parturition* (the act of giving birth) occurs. At this time the muscular walls of the uterus contract rhythmically with great force, and in this they are aided by muscular contractions of the abdominal wall. These contractions break the connection between the fœtus and placenta and the young are expelled through the vagina. The placenta is subsequently voided from the uterus in the same way.

The average duration of pregnancy or gestation is 116 days in the sow, 147 days in the ewe and 283 days in the cow. The pig has a relatively short gestation period, and is the only farm mammal capable of regularly producing two litters each year. Although the ewe is potentially capable of producing two crops of lambs per year, the limited duration of the breeding season precludes this in most cases.

Fertility. High levels of fertility are the basis of economic success in any form of livestock production. For the different classes of stock different standards are proposed. A sow should produce two litters per year, with nine or ten pigs reared from each litter. The cow should produce a calf each calendar year. The lambing percentage in sheep, i.e. the number of lambs reared expressed as a percentage of the number of ewes mated, should be 150 on lowland farms.

Fertility is controlled by several factors :

1. Age at sexual maturity, which determines when the animal can be first used for breeding. Gilts are normally mated at 8 to 12 months old, ewe lambs at 6 to 10 months (on lowland farms) and heifers at 15 to 20 months.
2. Ovulation rate (the number of ova shed from the ovaries at ovulation). Cattle normally ovulate one ovum, but double ovulations sometimes occur. Ovulation rates in sheep fall within the range of 1–3 depending upon breed and nutrition ; generally the higher the ovulation rate the more lambs will be born. The sow may ovulate as many as 30 ova but, again, breed and nutrition are important.
3. The number of ova fertilised. Failure of fertilisation may imply either that the male or female is infertile, or that the timing of mating was incorrect. Incorrect timing may be a cause of poor fertilisation rates where artificial insemination is used.
4. The number of fertilised ova which develop successfully to produce viable young. Sometimes diseases may result in the death of the fœtus, e.g. contagious abortion of cattle caused by *Brucella abortus*, but some fœtuses die and are reabsorbed by the dam when no disease organism can be identified ; up to 40 per cent of fertilised ova may be lost in this way.
5. The length of useful breeding life.

Artificial Insemination (A.I.). A.I. involves the collection of semen from the male and its insertion into the female reproductive tract during heat or œstrus. For the collection of semen the male is generally allowed to serve into an artificial vagina from which the semen can be recovered. Insemination of the female is carried out by trained inseminators, who insert semen into the female tract (either the uterus or vagina), using special syringes.

The large-scale use of A.I. in this country began in cattle in 1942 and has become particularly important in dairy cattle. The majority of bulls used in A.I. are stationed at centres controlled by the Milk Marketing Board. Artificial insemination of cattle results in conception rates which are similar to those achieved by natural service, and it is possible to dilute semen (with semen diluents such as egg yolk-phosphate, egg yolk-citrate or milk preparations) by 50 to 100 times without any appreciable loss of fertility. This is important because bulls of proven ability can be used to inseminate large numbers of cows. Further, in 1952 a technique was developed whereby semen could be stored for long periods at low temperatures by the addition of glycerine to the semen and freezing to −78° C. Semen stored by this " deep freeze " technique has shown only a slow decline in fertility even after several years' storage. The technique has made it possible to preserve semen from outstanding bulls for use after the bull itself has died.

Now that bulls can be used on such an extensive scale it has become necessary to carry out extensive progeny testing (see p. 485) so that bulls of outstanding genetic merit can be discovered.

A.I. in sheep has not been used to any great extent in this country, though it has proved successful on a large scale in Russia and has been used in trials in Australia and South America. The development of a successful technique for pigs has proved difficult, but recent successes suggest that A.I. may be widely used for pigs in the near future.

Lactation. In early post-natal life the young animal is entirely dependant for its nutrition on milk produced in the mammary gland. The development of the mammary gland is under the dual control of œstrogen and progesterone, and is synchronised with pregnancy so that a supply of milk becomes available at parturition.

The udder is composed of secretory tissue associated with some fatty and connective tissue, and milk leaves the udder through teats situated on its ventral surface. In the sheep and cow the udder is suspended from the posterior region of the ventral surface of the abdomen, but in the pig it may extend over most of the ventral surface of the abdomen.

Although the sow and ewe produce only sufficient milk for their young, scientific breeding and feeding of dairy cows have resulted in a level of milk production far in excess of the needs of the calf.

REPRODUCTION IN BIRDS

The reproductive organs and the processes of reproduction in birds are different from those of the mammal. In the male the testes are retained within the abdominal cavity : the male copulatory organ consists of a pair of papillæ projecting into the cloaca which enter the female cloaca during mating. Another important difference is that semen retains the power of fertilisation for several days after mating. (Fig. 112).

Castration of the cockerel produces a heavy, fat bird known as a capon which is suitable for the table, but castration by surgical means is not usually practised. Normally cockerels are " castrated " by implanting pellets of female sex hormone beneath the skin of the neck ; these inhibit androgen production from the testes and produce the same effects as removal of the testes.

In the female only the left ovary normally develops. At ovulation the whole of the ovarian follicle passes into the oviduct, the egg is coated with a thick layer of albumen (the white of the egg) and a hard chalky shell is formed around it. There is no œstrous cycle comparable with that of the mammal, and eggs are laid at roughly daily intervals.

Development of the fœtus takes place within the egg, all the nutrients necessary for fœtal development being present in the egg when it is laid.

THE PATTERN OF DEVELOPMENT OF ANIMALS

Comparisons of young and adult animals of the same species reveal that the young animal is not merely a smaller edition of the adult but has a different form. These differences occur because, during development, the different tissues, organs and regions of the body develop at different rates. For example, there is an early phase of rapid development of nervous tissue, followed by bone, then muscle and finally fat. Also different regions of the body show an ordered development. A primary wave of growth passes from the skull anteriorly to the facial parts and then posteriorly to the loin (the region of the lumbar vertebræ). Secondary waves pass from the extremities of the limbs towards the body and ultimately converge on the loin. Finally, if the rate of development of different organs is compared, it is found that organs which are required to function early in life, e.g. the brain, eyes, heart, liver and kidneys, develop earlier than an organ, such as the rumen, which does not function until some time after the animal is born.

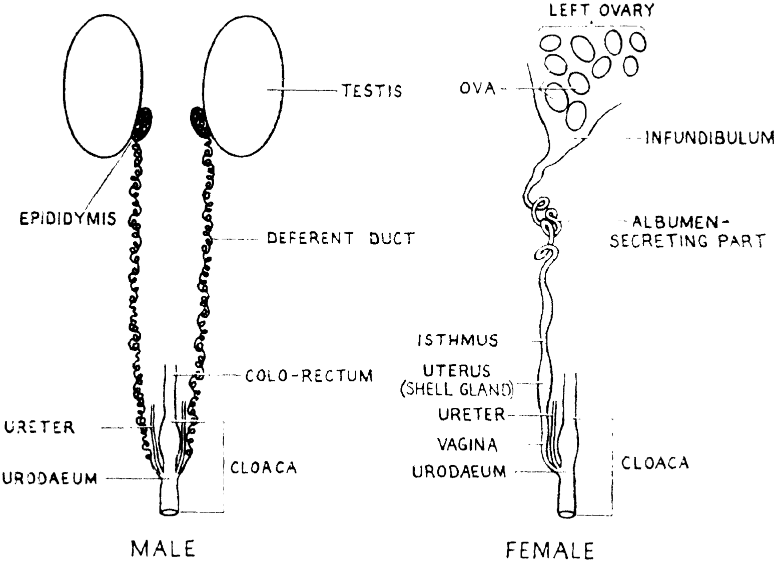


FIG. 112.—REPRODUCTIVE SYSTEM OF FOWL (DIAGRAMMATIC).

These developmental effects become evident early in fœtal life and result in an animal which, at birth, has a relatively large head and long limbs (with the extremities as their best developed parts) but a rather narrow, shallow trunk with a poorly developed loin region. In post-natal life the regions which are poorly developed at birth develop rapidly until the animal assumes its adult form.

The pattern of growth and development may be modified by various factors. Firstly, some breeds develop more rapidly to maturity than others, and this is of prime importance in animals being used for meat production. Secondly there are marked differences in size and appearance between males and females of the same species. And finally, nutrition has fundamental effects on the rate at which animals grow and develop.

Chapter XVIII

FOODS AND FEEDING

THE GENERAL CHEMICAL CHARACTER OF FOOD

All materials used as food for animals come directly or indirectly from plants. In some cases the whole plant—leaf, stem and root—is consumed, but in most cases the individual foods consist of only parts of plants, either " as grown " or after treatment in which some part may have been removed (e.g. in the milling of grain). The small, but very important, class of feeding-stuffs that are directly animal in origin (e.g. milk and milk products, meat meals, etc.) have themselves been produced by the consumption of vegetable matters by other animals.

Water. Whatever its immediate origin every feeding-stuff is a very complex mixture of chemical compounds, some of them simple, others complicated in chemical constitution. The simplest ingredient, which is common to all foods, is *water.* The proportion of this may range down from 95 per cent in some " succulent " foods (e.g. soft turnips) to 10–15 per cent in " air-dried " foods, or lower still in " heat-dried " foods. Water itself does not perform any of the functions of food, but is of the highest importance for the life and health of the animal, and for the utilisation within the animal of the food proper which is provided by the *dry matter* supplied along with it in the foodstuff. The role of water in nutrition is discussed later in this chapter.

Organic Matter and Mineral Matter. By far the greater part (90 per cent or more) of the dry substance consists of *organic matter* (i.e. material which can be burnt away, or oxidised), the rest consisting of a mixture of *mineral matters* (ash). The basic explanation of the differences in nutritive characteristics and value of different feeding materials lies in the nature and proportions of the various chemical compounds of which these two main sub-divisions of the dry matter are composed.

Mineral elements are found in every tissue and fluid of the animal body and its products, some being essential to the proper functioning of the body metabolism, whilst others are apparently not essential, though not necessarily useless if present. Apart from the need in appreciable quantities of certain mineral elements (notably calcium and phosphorus) for the structural needs of the animal, the functions of the mineral matters resemble those of the water, in that they do not so much function as " food " but as activators and regulators of the food utilisation processes and of the efficient working of the bodily organs.

The food proper is thus confined entirely to the organic matter, and a knowledge of the nature and functions of this part of the animal's dietary is consequently necessary for an understanding of the nutritive value of a feeding-stuff or ration, and an efficient control of its use.

The Analysis of Feeding-stuffs. In terms of the number of different chemical compounds present in even the simplest-looking feeding-stuff, the organic matter is so complex that any attempt to ascertain the proportion of each separate chemical compound present in it would be a matter of prolonged research for the chemist.

For the practical purposes of the farmer and the feeding-stuffs trader, however, it is essential that the chemist shall be able to give guidance fairly quickly as to the composition of the different food materials submitted to him. For these purposes, therefore, a simplified scheme of analysis is used which, though based upon assumptions which are never entirely accurate, gives data which have been proved by long experience to be reasonably adequate for the practical purposes of the farm. The most important of these assumptions are (1) that all nitrogenous compounds in foods are proteins containing 16 per cent nitrogen ; (2) that all ether-soluble matters in foods are fats. Because of these uncertainties scientists prefer in setting out the results of analysis the modified terminology for the items that are shown to the right of the example given on page 527.

This analytical scheme takes advantage of the fact that almost the whole of the chemical compounds which make up the organic matter of foods belong to the three great chemical groups or " families " of *carbohydrates*, *fats* and *proteins*. Each group is sharply differentiated from the others ; within each group there is sufficient resemblance between the individual members in composition and nutritive characteristics to make it possible for practical purposes within wide limits to treat each group as a nutritional unit. Visualised along these lines the composition of the food can be set out as indicated in the schedule below.

$$\text{FOOD}\begin{cases}\text{DRY MATTER}\begin{cases}\text{MINERAL MATTER } (\textit{Ash})\\ \\ \text{ORGANIC MATTER}\begin{cases}\text{PROTEINS}\\ \text{FATS}\\ \text{CARBOHYDRATES}\\ \text{SUNDRY INGREDIENTS}\end{cases}\end{cases}\\ \text{WATER}\end{cases}$$

The scheme of analysis in common use in all countries is based upon the foregoing schematic conception of the composition of food, with the modification that the carbohydrate item is sub-divided into *soluble carbohydrates* and *crude fibre.* Furthermore, since the particular scheme of analysis adopted involves the embodying of the " sundry ingredients " item in the " soluble carbohydrates " figure, the latter is commonly returned as " soluble carbohydrates, etc.". A further extension sometimes made is to divide the " protein " figure (described as " crude protein ") into " true protein " and " non-protein nitrogenous matter " or " amides ". Another refinement is to indicate the proportion of sand, etc. (dirt), present in the ash of the food.

A typical analysis of wheat grain carried out according to this scheme in full might thus be set out as follows :

ANALYSIS OF WHEAT GRAIN

	Per cent.	
Water	12·8	(= Loss of weight at 100° C.)
Crude protein	11·9*	$\left(= \text{Total N} \times \frac{100}{16}\right)$
Fats	1·9	(= Ether extract)
Sol. carbohydrates, etc. . .	69·6	(= Nitrogen-free extractives)
Crude fibre	2·0	(= Fibre)
Mineral matters (ash) . .	1·8†	(= Ash)
Total . . .	100·0	
* Including True protein	11·1	$\left(= \text{Protein N} \times \frac{100}{16}\right)$
" Amides " or non-protein nitrog. subs.	0·8	$\left(= \text{Non-protein N} \times \frac{100}{16}\right)$
† Including sand, silicious matter, etc.	0·2.	

In carrying out the analysis, direct determinations are made of five of the six items, viz. water, crude protein, fats, crude fibre and mineral matters ; the remaining item—soluble carbohydrates, etc.—is then arrived at by difference, i.e. by subtracting the sum of the five directly ascertained percentage data from 100. Carbohydrates form by far the most abundant group of food ingredients in the great majority of our feeding-stuffs, and it is unfortunate therefore that a direct determination of their amount cannot readily be made. The difference figure must necessarily carry the full weight of the combined errors in the results obtained in the five direct determinations made. These errors may or may not cancel each other out, but in any case the practical effect will be serious only in the case of foods poor in carbohydrates.

Attention has already been drawn to the further effect of the difference method in embodying in the carbohydrate figure any non-carbohydrate ingredients of the organic matter of the food other than proteins, fats and fibre. The vitamins of the food, for example, will mostly be included in this figure.

For a more detailed critique of the current scheme of analysis here outlined reference must be made to textbooks of agricultural chemistry. This applies also to the detailed exposition of the chemical characteristics and metabolism of the various classes of ingredients present in foods. In this chapter it is only necessary to outline the main features upon which rest the practical utilisation and value of foods.

THE CONSTITUENTS OF FEEDING-STUFFS

Carbohydrates. The carbohydrate group comprises a very large number of individual members, all composed of the three elements carbon, hydrogen and oxygen, present in proportions corresponding to the general chemical formula, $C_x(H_2O)_y$, where x and y may be the same or different numbers. For the purposes of animal nutrition the only class of carbohydrates of any appreciable value are those in which x is either 6 or some multiple thereof (hexosans). Apart from these, the only other class of carbohydrate present in foods in more than very small proportions, if at all, is the five-carbon class (pentosans), of which coarse fodders, husks and seed coatings may contain appreciable quantities. They are mainly contained in the fibre fraction of the food, but beyond the heat arising from their oxidation it is doubtful whether they contribute much to the needs of the body.

Of the hexosans the most valuable are the sugars, dextrins, starches, hemi-celluloses and celluloses. Of these the sugars are the simplest in chemical constitution and fall mainly into the two classes of the *glucose* group ($C_6H_{12}O_6$—glucose, fructose, galactose) and the *sucrose* group ($C_{12}H_{22}O_{11}$—sucrose, maltose, lactose). They are all soluble in water and of high nutritive value, but being readily attacked by bacteria are apt to suffer some loss in the digestive tract before they can be assimilated.

The carbohydrates of the highest nutritive value are those of the starch class [$(C_6H_{10}O_5)_n$] since they are rather more concentrated in energy-yielding elements (C, H) than the sugars and being less soluble suffer rather less waste by bacterial action.

The digestive juices contain enzymes which quickly digest the sugars and starches, but they do not contain any enzyme capable of digesting the more complex celluloses and hemi-celluloses. In so far as the latter can furnish useful nutritive material, therefore, it can only be through the agency of bacteria, and can only occur to any considerable extent when there is abundant opportunity for vigorous and prolonged bacterial activity in the digestive tract, as in the rumen of cattle and sheep. Under such conditions some part of the cellulose is converted into volatile organic acids that can be assimilated and made useful for nutritive purposes. It is in the form of such products that the useful material digested from the carbohydrates, whether sugar, starch or cellulose, enters the bloodstream and is applied to meet the needs of the body.

Owing to the great preponderance of carbohydrates in the food-supply, even in diets of relatively low carbohydrate content, and the readiness with which they liberate their energy in the metabolic processes as heat and other forms of energy, the carbohydrate group makes by far the greatest individual contribution to the needs of the animal for both maintenance and production purposes, whether the production takes the form of growth-, milk-, work- or egg-production. Even in the fattening animal the greater part of the fat laid down originates from the carbohydrates digested from the food.

Fats resemble the carbohydrates in being made up entirely of carbon, hydrogen and oxygen, but differ sharply from them in being far more concentrated in carbon and hydrogen, and correspondingly poorer in oxygen, and consequently being more concentrated in stored-up energy which can be placed at the disposal of the animal. Measured in terms of the heat given out on complete oxidation, fats are nearly 2½ times as concentrated in energy as carbohydrates. Economic and dietetic considerations, however, usually restrict greatly the proportion of fat that can be effectively included in the food and, except in the milk-feeding of young animals, it is unusual to find more than about 5 per cent of fat in the rations used in farm practice. Within the limits thus imposed upon their use the fats can discharge the same functions in energy supply and fat production as the carbohydrates.

Fats are chemical combinations of glycerine with organic acids. A pure fat may contain one, two or three acids, but most natural fats are mixtures of fats and therefore may contain many more acids in their make-up. These acids are of two general chemical types—*saturated* and *unsaturated* ; those of the former type found in fats are mostly solid within the ordinary range of temperatures of the temperate zones, whereas the unsaturated acids are liquid down to much lower temperatures. This difference is reflected also in the texture of the fats containing them in combined form, the fat tending to be softer the higher the proportion of unsaturated to saturated acids present in it. Whether by direct transference or indirectly, the food fat tends to impress its character in this respect upon the animal fat, whether body-fat, milk-fat or egg-fat. It thus has a hardening or softening effect which may need to be taken in account in feeding practice when fat texture is an important factor in the assessment of the quality of the product, as in the production of bacon and butter. This influence of the food fat seems to be more directly exercised through the unsaturated than the saturated acids and, generally speaking, it is easier to produce softening than hardening effects.

In the fats group as a whole by far the most abundant fatty acids are the two saturated acids, stearic and palmitic acids, and the unsaturated acid, oleic acid, the former tending to preponderate in the solid fats and the latter in the soft and liquid fats (" oils ").

Proteins. Although from the point of view of chemical constitution the proteins are the most complicated of the three great groups of nutrients, they are little more complex than the carbohydrates and fats in terms of the chemical elements from which their complex structure is built up. The differences, however, are very significant and important, especially the presence, along with the carbon, hydrogen and oxygen, of some 15 to 18 per cent of nitrogen in the make-up of the protein molecule. In some cases the mineral elements sulphur (up to 2 per cent) and phosphorus (up to 1½ per cent) are also present. Clearly therefore, in so far as nitrogen enters into the composition of the animal body and its products, the supply of it must be a special charge upon the food-supply, and in particular upon the proteins present in it, since there is no other class of ingredient present in it in more than small proportions that contains nitrogen. It is hardly an exaggeration, therefore, to make the generalisation that nitrogenous substance in the body can only come from proteins in the food. On a full diet consisting only of fats and carbohydrates, an animal would assuredly die of nitrogen starvation.

Amino-acids. In the plant the protein, starting with carbon dioxide, water and simple nitrogenous compounds (ammonia, nitrates), is built up in progressive stages into more and more complicated compounds until eventually the perfected protein is produced. At one stage in this building-up process the various products then formed belong mainly to the two chemical classes of amino-acids and amides. When the protein is consumed by the animal the protein-digesting enzymes or proteases break it down mainly to this particular stage and no further ; the amino-acids and amides are then assimilated into the blood-stream and there rebuilt into animal proteins. These intermediate constituents of the proteins, of which more than 20 have been identified, are the protein-building units upon which the animal depends. In their value to the animal the importance of the individual units varies, some being absolutely essential, whilst others, though possibly useful if present, are not essential to the protein purposes of the animal.

Protein "Quality". The amount and kind of the different amino-acids, etc., present in different proteins varies widely, and one or more of them may be completely missing from some proteins. If the missing item chances to belong to the essential class, then that protein by itself clearly cannot serve efficiently as the only source of protein, but must be blended with another protein whose digestion products will supply the missing item. This is one of the many reasons why in feeding practice it is safer to include a variety of foods in the ration rather than depend too much upon one or two particular foods. Variety as a safeguard of protein efficiency is determined by the origins rather than the commercial descriptions of the foods. Thus a mixture of maize, maize germ meal and maize gluten feed does not ensure protein variety, whereas a mixture of maize, palm kernel meal and bean meal does.

Even this mixture is not nutritionally complete because recent research shows that proteins of animal origin (e.g. in fish meal, milk, dried blood) contain a factor (the Animal Protein Factor or A.P.F.) which is essential for the normal growth and well-being of the young animal, especially for non-ruminants like pigs and poultry.

Intensive work on this factor resulted in 1948 in the discovery of a pure chemical substance containing the element cobalt which was extracted from liver tissue. Not only is this compound extremely potent in promoting growth but it is also specific against pernicious anæmia in man. On this account it is now classed with the vitamins and is known as vitamin B_{12}. Vitamin B_{12} is not the only component of the A.P.F. but it is certainly a very important one.

Vitamins. All foods contain organic ingredients which are not properly classified as proteins, fats or carbohydrates, and which, as explained above, are mainly embodied in the "soluble carbohydrate, etc." item given by the conventional food analysis. These ingredients are mostly present only in very small proportions, and until the opening years of the present century their presence was largely ignored in the consideration of nutritional problems. Modern research is steadily revealing, however, that some of these items have a profound bearing upon, and are essential to, the efficient metabolism of the major nutrients. Details of the nature and nutritional significance of these items will be found in textbooks of agricultural chemistry, and it must suffice here to outline the salient points concerning one particular group of ingredients which has aroused more widespread interest than any other—the *vitamins*.

Evidence had long been accumulating that the supply of proteins, fats, carbohydrates and minerals, although certainly the major part in terms of quantity, did not cover the whole of the requirements of the animal from its food, and in particular that certain specific forms of ill-health, such as rickets and scurvy, were attributable to deficiencies in the make-up of the diet. Conclusive experimental evidence of the correctness of this view was not obtained, however, until the early years of the century, since when it has been abundantly justified and amplified. In default of knowledge as to the precise chemical nature of these essential ingredients, the term " accessory factor " was at first applied to them, but this was soon replaced by the simpler term " vitamin ", which has now become the class name for the numerous substances of this type that have since been discovered. It should be noted, however, that, unlike the proteins, etc., the vitamins are not grouped together on grounds of chemical similarity, but on the basis of the kind of effect that their absence or shortage produces in the animal.

At first, until the precise chemical nature of the individual vitamins could be established, chemists agreed to name them simply by letter, as vitamin A, vitamin B, etc. When further investigation showed that what were being regarded as single ingredients were really mixtures of vitamins, the A, B, C, etc., became group denominations, and the different items within each group were distinguished by numbers, e.g. A_1, A_2, A_3, etc. ; B_1, B_2, B_3, etc. This nomenclature is still widely used, but with the growing knowledge of the chemical nature of the individual items, the present tendency is to replace it by specific names, often indicative of the chemical nature of the vitamin.

On the farm the risks of vitamin shortage of any serious consequence vary with the class of animal, the system of management and the season of the year. Broadly speaking, they are less with ruminants than non-ruminants, with outdoor than indoor systems, and in summer than in mid-winter. The groups of vitamins of which our present knowledge is the most extensive are vitamin A (growth-promoting) ; B (anti-neuritic and growth-promoting) ; C (anti-scurvy) ; D (anti-rickets), and E (anti-sterility). The vitamins A, D and E are fat-soluble ; B and C, water-soluble.

In ordinary farm practice trouble due to deficiency of vitamins of the C and E groups is rarely met with, but in some " intensive ", largely indoor, systems of management the supply of the A, B and D groups needs to be watched, whilst in poultry feeding, especially in chick-rearing, the supply of other vitamins not listed above may need attention. A brief outline of points of practical interest in relation to the A, B and D vitamin groups follows.

Vitamin A is essential to life and to the production and repair of tissues that are essential to growth and maintenance. It is thus of special importance in the feeding of growing animals and in the milk designed for their early support. Its lack or deficiency is claimed to lead to increased susceptibility of the animal to bacterial infection, and therefore to disease, but this is due rather to its general effect upon the health of the animal than to any specific anti-infective action.

It can be produced in the animal from the yellow pigment, carotene, which occurs in green plants along with the chlorophyll; such materials containing carotene thus serve as important sources of vitamin A for the animal. In the form of the vitamin it occurs only in animal products and in association with the fats, especially liver oils (e.g. cod liver oil). Whether supplied as carotene or preformed vitamin, if the supply is adequate some part of it passes into the animal products, such as milk and eggs, and a reserve supply is accumulated in the liver. In the case of the pregnant female a similar reserve is stored in the liver of the fœtus.

It is fairly resistant to heat but gradually loses its value when exposed for long to the air. For this reason the pre-mixing of vitamin A or carotene supplements with food is to be deprecated unless the mixture is to be consumed without much delay.

A characteristic effect of vitamin A deficiency is a tendency to night blindness and other eye defects, together with the development of sores in the throat and mouth. In the young animal growth is retarded and in severe cases may cease entirely.

Vitamin B. The vitamin B complex comprises at least six water soluble vitamins. Vitamin B_1 (Thiamine), the antineuritic vitamin, is not stored up in the body and hence must be entirely supplied through the food, except in ruminants, since these can derive their B_1 supply from bacterial synthesis in the rumen. It is present in a wide variety of foods, particularly brewer's yeast and wheat germ. Cereal grains, young fodder, liver, kidney and egg-yolk are well supplied with it.

Symptoms of its absence from or deficiency in animals are loss of appetite, and retardation or cessation of growth, followed by the development of paralysis and early death. Lack of it may lead to sterility in both sexes.

Of the other vitamins comprised in the vitamin B complex the best known is *riboflavin* (or B_2, or in America, vitamin G). Like B_1 it can be synthesised by bacterial action in the rumen, but must be supplied pre-formed in the food of non-ruminants. It is present in appreciable amounts in green leafy fodders, oil meals, meat meals and yeast. Cereals and their by-products are less well provided with the B_2 than with the B_1 vitamin. Dried yeast and milk, especially separated milk and whey, are relatively rich in this vitamin.

The symptoms of B_2 deficiency vary widely in different animal species, apart from the general tendency common to many vitamins of inducing lower growth rates and unsatisfactory consumption and utilisation of food. In chicks the most characteristic symptom is "curled-toe paralysis", often accompanied by diarrhœa. In laying birds the most obvious symptoms are low egg-production and poor hatchability. In pigs, a B_2 deficiency often causes stiffness of the joints and skin eruptions.

Vitamin B_{12}, already referred to as the major constituent of the so-called "Animal Protein Factor" (A.P.F.), is essential for optimum growth in the young animal, and is likely to be required as a special supplement where the diet consists almost entirely of vegetable foods. Good sources are fish and meat meals, fish solubles, dried blood and cow's milk. Commercial vitamin B_{12} is usually produced by fermentation with a specific mould organism such as *Streptomyces griseus*. Incidentally the products of decomposition of organic matter by fermentation have now assumed major importance in nutrition as well as therapeutics and are known as *Antibiotics* (see p. 539). Vitamin B_{12} is synthesised by bacteria in the paunch of ruminant animals and it is more than likely that the available supply of cobalt in the herbage consumed limits the production of this important substance and hence the ability of the animal to digest its food (see p. 537).

Vitamin D, which like vitamin A is fat-soluble, was found, when separated out from the original vitamin A, to have specific effects in warding off the disease of rickets. It does this through its influence upon the deposition of calcium and phosphorus in the bones. Apart from this connection with bone growth the D vitamin is in other ways essential to health. Later research has shown that there are at least four different forms of it, of which the most important in practice are D_2 and D_3, the latter being the form especially required by growing chicks.

The amount required to ensure healthy bone development varies with the mineral composition of the diet and also with the species of animal. Broadly speaking the amount of vitamin D required is lowest when the ratio of calcium to phosphorus lies between 2 : 1 and 1 : 2, but no amount of vitamin will compensate for actual deficiencies of either mineral. The role of vitamin D is much less important in the adult than in the growing animal, except for the female during periods of reproduction and lactation.

The long-known therapeutic value of sunlight in the treatment of rickets found an explanation, perhaps only partial, in the discovery that one or more of the D vitamins can be produced by exposure of the skin of the animal, or of many foods, to certain of the ultraviolet radiations from the sun or from special types of artificial light that are rich in these rays. The vitamin is produced in this way from substances of the sterol class that are present in small proportions in the skin or the foods irradiated. From this possibility one may rightly infer that in the tropical and temperate zones animals that live wholly, or in substantial part outdoors, are unlikely to be short of vitamin D, except possibly under winter conditions. In the case of animals kept indoors, even in well-lighted quarters, the effects of irradiation will not be obtained unless the windows are glazed with special glass (" vita-glass ") and kept clean, or preferably so constructed that they can be thrown wide open in fair weather.

The symptoms of rickets in the young are the familiar deformation of the leg bones, accompanied by swellings and tenderness of the joints. In adults, if the deficiency is prolonged, the bones become brittle and easily broken, and in laying fowls the thickness of the eggshell is reduced. In very severe cases the effects may develop to the stage of paralysis.

The best natural sources of vitamin D are animal fats, liver, and certain fish liver oils (e.g. cod liver oil), whilst, as indicated above, many foods (notably yeast) may be " reinforced " with the vitamin by irradiation. Growing greenstuffs do not contain the vitamin, but after cutting and exposure, as in haymaking, a certain amount of it may be produced in them.

Vitamin E has been found to be essential to reproductive activity under experimental conditions, but information is still very scanty as to the extent to which deficiency of vitamin E may be a causative factor of sterility in farm animals kept under farm conditions.

It is a fat-soluble vitamin, and is widely distributed in the common foods, especially in green fodders and other leafy materials. It is also present in seeds, especially in the germ. Many vegetable oils contain it, wheat germ oil being regarded as the most concentrated source.

Chemically, vitamin E acts as an antioxidant and as such may suffer destruction in foods under conditions which favour oxidative processes.

The condition known as muscular dystrophy in calves, and also that recognised as crazy chick disease in chickens, are associated with a deficiency of vitamin E.

Mineral Matters. The animal body contains a considerable variety of mineral elements, many of which have been shown to be essential to its efficient working. Until recent years the list of essential mineral elements was thought to be confined to the elements sodium, potassium, calcium, magnesium, iron, phosphorus, chlorine, sulphur and iodine ; but to these must now be added manganese, copper, cobalt, zinc, fluorine, and possibly others may still have to be included. These additions to the old list share with the vitamins one feature in common, in that they are required only in extremely small proportions, and may have detrimental effects if supplied in excess.

Our knowledge of the precise function of each element and of the amounts needed by the animal is in most cases still very inadequate. Of the mineral elements that are required in (for minerals) relatively large amounts the lead is taken by potassium, calcium and phosphorus, followed by sodium and chlorine, then by iron, magnesium and sulphur, and finally by the rest, most of which are only needed in such minute amounts that they are commonly referred to as " trace minerals ".

Some of the mineral elements are present in both the food and in the body both as mineral salts and combined in organic forms. Thus the sulphur, which appears in the ash wholly as sulphates, is present in the original plant or animal matter almost entirely in organic forms (e.g. proteins) ; the same applies also in the case of phosphorus (except in ash from bones).

Foods used on the farm vary greatly in their mineral make-up. As a broad general rule the vegetative parts of plants are richer in mineral elements than the seeds ; the dry matter of young greenstuffs is richer in useful minerals than that of maturer vegetation ; that of " roots " is relatively rich in soluble minerals. Animal products used as food, unless they contain bone, show mineral contents, expressed as ash, ranging roughly from 3 per cent (dried blood) to 7 per cent (dried milks) ; but in these cases all the ingredients are useful and readily assimilated, whereas in foods of vegetable origin the ash usually includes a proportion of useless ingredients.

The general functions in the body of the essential mineral elements are varied and complex. Some of them are essential to the structural soundness of the bones and teeth. The soluble salts serve a variety of functions in the blood and other body fluids, such as the maintenance of normal pressure relations and the desirable balance of acidic and basic elements. They also play a part in regulating the activities of muscles and nerves. Apart from such general functions discharged by groups of minerals, each mineral element has specific roles, such as those outlined below.

Calcium and Phosphorus, which together make up more than 70 per cent of the ash of the body, are so closely associated in metabolism that it is convenient to consider them together. Reference has already been made (p. 533) to the necessity for a suitable balance between the supplies of calcium and phosphorus for sound bone formation, as well as the co-operation of vitamin D. They are particularly abundant in the bones and teeth, which together contain about 99 per cent of the calcium and 80 per cent of the phosphorus present in the body. This high proportion of calcium phosphate in the bones not only assists in conferring strength and rigidity, but also serves as a reservoir of calcium and phosphorus out of which temporary shortages of these elements in the food may be made good. Although the proportions in the soft tissues and fluids are thus only small, they are widely distributed and play parts of fundamental importance in the body metabolism. Reference has already been made to the fact that the phosphorus is mainly present in organic combinations, such as some of the proteins ; this applies also to some extent to the calcium.

The concentration of calcium in the blood, though low, is a matter of importance, and is controlled by a special agent or hormone produced by the parathyroid glands. Low blood calcium leads to tetany and may be a contributory cause of milk fever and rickets ; high calcium leads to unduly rapid drain of calcium from the reserve in the bones.

Foodstuffs vary widely in their content of these two elements. Broadly speaking, all seeds and products derived from them are poor in calcium in relation to animal needs, but relatively rich in phosphorus. The content of grass and roughages varies with the soil, manuring and conditions of growth, leguminous produce being generally richer in calcium, but less regularly so in phosphorus, than non-leguminous. Outstanding in high content of both elements are naturally the animal by-products containing bone (meat meal, fish meal). Dried separated milk also ranks as a valuable source of the two elements.

In view of the relatively large amounts of calcium and phosphorus required by the animal—especially where growth, milk-production and egg-production are concerned—and the consequent frequency with which deficiencies of supply of these minerals are liable to arise in practice, the addition of mineral supplements to rations has become common. For this purpose fine bone meal and precipitated bone flour are useful in supplying both elements. If mineral phosphate is used for the purpose, care should be taken to avoid material containing more than about ½ per cent of fluorine, since this element, commonly present in mineral phosphates, though essential to the animal in minute proportions, exercises a cumulative toxic effect at higher levels of intake.

Magnesium occurs in the body in much smaller proportions than calcium and phosphorus, but is closely associated with them (especially phosphorus) in its metabolic action. It is essential for the production of sound teeth, and may play a part in connection with rickets which may be helpful or harmful according to the amount fed and the relations of the calcium and phosphorus present in the diet. The possible effect of magnesium deficiency which has attracted most attention is its apparent association with certain types of tetany, such as lactation tetany and grass tetany, to which grazing animals are sometimes subject and which are often accompanied by subnormal magnesium content of the blood. Other dietary factors probably enter also into the causation of this type of trouble.

Potassium, Sodium and Chlorine form another group of elements which, severally and collectively, play important parts in the body functions. They occur almost entirely in the soft tissues and fluids, potassium predominating over sodium in the tissues, and the reverse in the fluids, with the outstanding exception of milk. Together, the three elements exercise a very important influence upon the movements and utilisation of water in the body. In chemical character sodium and potassium are both powerful bases (alkalis) and in some of their actions are to a certain extent mutually replaceable.

Potassium exercises an influence upon the metabolism of carbohydrates, and a marked, but as yet little understood, influence upon muscular activity. Since it is relatively abundant in all plant products it is probably only rarely that potassium deficiency will cause a practical feeding problem on the farm, except possibly where high milk production coincides with deficient potash manuring.

Sodium, as above mentioned, is the dominant basic element of the body fluids and is thus largely responsible for the maintenance and regulation of a suitable base–acid ratio in them. It is not stored in the body, and any excess of supply is rapidly removed mainly through the kidneys, but also to some extent in perspiration.

Chlorine, an acidic element, is present in the body partly in organic combination, but mainly in combination with bases as chlorides, principally sodium chloride (salt). The fact may also be recalled that the gastric juice contains chlorine both as a small percentage of hydrochloric acid and as chlorides (see p. 506).

The importance of common salt in the human dietary has been recognised from ancient times, and the practice of making it available to farm animals, especially to milch cows, is also of very long standing. The body has the power of adjusting itself within wide limits to the intake of salt, and any serious effects of an actual deficiency may be revealed only very slowly in unthriftiness, loss of weight, and fall in milk yield. The moderate condimental use of salt tends to stimulate the secretion of saliva and to promote the action of the starch-digesting enzymes, whilst its excessive use leads to the familiar development of thirst, owing to the large amounts of water then needed to remove the excess of salt. Owing to the character of the basic foods consumed by them, cattle have a relatively greater need for salt than pigs or poultry, but because of the great preponderance of salt-poor cereals and cereal products in the common dietaries of the latter classes of stock, the addition of a little salt is often necessary to ensure optimum feeding results.

Iron, although present in the body to the extent of only about 4 parts per 100,000, is of vital importance through being a constituent element in the make-up of the red colouring matter of the blood, hæmoglobin, by means of which oxygen is absorbed from the air inspired by breathing, and so carried to all parts of the body (see p. 508). Small amounts of iron in other active forms are also present in the body, whilst a small amount is stored in the liver and kidneys.

Deficiency of iron is the main cause of the type of anæmia termed "nutritional anæmia", which may occur at any time of life but arises most frequently in quick-growing species of animals during the period of suckling, since milks are very low in iron. On the farm this trouble is common only in suckling pigs, and can be averted or remedied by administration of a little iron (plus a trace of copper) direct to the young animal. The iron content of the mother's milk cannot be raised by addition of iron to her food. When the young animal begins to eat other food, the risk of anæmia quickly passes away since most of the farm foods are liberally supplied with iron in proportion to the needs of the body.

Copper is required in minute amounts because without it the hæmoglobin does not function effectively, though the precise role of the copper is not yet clearly understood.

In farm practice copper-deficiency only arises in areas where the natural herbage is so poor in copper that even the very small needs of the grazing stock are not met. Such areas have been identified in several parts of the world, especially in north-west Europe and Australia, and parts of the hill-regions of northern England and Scotland (see p. 647).

Cobalt is now regarded as an essential element of food because it is a component of the important vitamin B_{12}.

Though the actual amount of cobalt required by animals is extremely small, both soil and herbage may be deficient in the element. Cobalt deficiencies are known to occur in certain areas throughout the world, and are associated with wasting diseases, such as pining (see p. 647).

Iodine is an important essential mineral element, because although the body as a whole may contain no more than 4 parts per 10,000,000, more than one-half of this is in one particular gland, the thyroid gland, which plays an essential part in the regulation of some of the most important vital processes, such as gestation, growth, egg-production and milk-production. This regulation is effected by means of the hormone, thyroxine, which is present in the internal secretion produced by the gland and contains a large proportion of iodine.

A marked deficiency of iodine causes the gland to swell up and the serious condition known as goitre develops. This trouble is particularly liable to develop in regions where the soils, crops and water-supplies are practically devoid of iodine, such as many districts remote from the sea ; but it is also met with in other districts where the soil iodine content is not particularly low, so that other factors are apparently also involved in the causation of goitre.

This serious risk involved in iodine deficiency has led to an exaggerated and indiscriminate tendency to add iodine supplements to diets regardless of any evidence of the need for them. Whether iodine deficiency in farm rations is sufficiently widespread and generalised to warrant this practice is doubtful, and the evidence from experiments is as yet conflicting, but on balance suggests that it is not common under ordinary conditions of management. Where an iodine supplement is thought to be necessary, it can be provided in the form of a few ounces of potassium iodide per ton of food.

Sulphur is a constituent of some of the animal proteins, and the amounts provided by the common varied diets appear to be adequate for the sulphur needs of the body. Sulphur-containing proteins (" keratins ") are notably present in horn, hoof, claws, feathers, skin and wool. Some of the essential amino-acids (e.g. methionine) contain sulphur.

Manganese is required in minute amounts for normal reproduction, and it has an influence on the rate of growth. In poultry its absence also gives rise to a specific malformation of the leg bones of growing chicks described as " slipped tendon " or perosis. Certain other mineral and organic factors are probably also concerned in the causation of this trouble, e.g. the supplies of calcium and phosphorus.

Zinc has been found to be an essential trace element in laboratory experiments with rats, and for the prevention of an unhealthy condition of the skin, known as " parakeratosis " in pigs. Trouble can arise in practice from its toxic effects if present in more than minute amounts. A few such cases in pig feeding have been reported.

Fluorine is another example of a mineral element that is apparently essential in minute amounts, but seriously toxic at excessive, though still very low, levels of supply.

Aluminium and Silicon. Apart from the mineral elements listed as essential, foods will generally contain other mineral elements taken in from the soil, but exercising, so far as present knowledge goes, no essential function in the food. Outstanding in this respect are the elements aluminium and silicon, which are universally present.

In the case of silicon no essential function has been traced, although it enters extensively into the mineral metabolism ; nor does any harmful effect seem to develop from its presence in more than average proportions. Whether the presence of aluminium in foods may be harmful or not is a matter of current controversy in relation to foods used for human consumption.

Toxic Elements. Certain other elements which may be present in foods grown in special areas are definitely toxic in their effects, e.g. arsenic, molybdenum, selenium, etc. Thus the presence of molybdenum in the herbage explains the scouring trouble experienced on the so-called " teart " lands of Somerset and Warwickshire (see p. 699).

Antibiotics. These are recently discovered chemical substances prepared from the products formed during the growth of certain moulds. Penicillin is the best known example, but others that have been found useful include aureomycin, streptomycin, terramycin, bacitracin and chloromycetin. Their original, and still principal, use was to control and dispel diseases of microbial origin—to act so to speak as disinfectants. It was found later, however, more or less by accident, that certain antibiotics possess growth stimulating powers, probably by reason of the control exercised over intestinal bacteria, although this may not be the complete explanation. Experiments with pigs and poultry in which very small amounts of selected antibiotic substances have been incorporated in the food (½ oz. per ton of food) have repeatedly given enhanced growth rates in young stock, usually of the order of about 10 per cent, while the medicinal value of these drugs (at a heavier rate than the above) has been demonstrated particularly with a fairly high proportion of runt pigs.

Additives. The major components of the mixed concentrate rations of all classes of livestock are concerned with meeting the energy and protein requirements of the animal. However the rations of today may include a number of minor factors at less than a 5 per cent level and very often below 1 per cent, and these exert an appreciable effect on the health and performance of the animal. Some of these minor factors are direct nutrients, such as sources of minerals and vitamins ; others have beneficial effects in widely different ways. These factors are usually referred to as " additives ", although it is virtually impossible to give a comprehensive definition of the term.

Amongst " additives " we may include such nutrients as vitamins, minerals and synthetic amino acids, the latter enhancing the value of the particular proteins of the food for certain species. Other additives may protect labile factors against loss through atmospheric oxidation and rancidity and are called *anti-oxidants* : these include " natural " substances such as vitamin E, or synthetic substances such as butylated hydroxyanisole (BHA). Some additives may have direct growth-promoting properties ; these include the antibiotics (at low level usage) and copper sulphate (for pigs) at specified levels. Other additives are used for directly controlling or preventing disease, such as the *coccidiostats* and the anti-blackhead group of drugs, and thus enable the animals fed on them to remain in sound health and make the fullest use of the food offered. Growth-promoting additives also include synthetic anti-hormone substances (e.g. thiouracil), synthetic hormones (e.g. hexoestrol), tranquillisers, surfactants, arsanilic acid derivatives and so on.

It is evident, then, that the term " additive " includes a wide and ever-increasing range of substances that broadly are used to promote health and well-being and to stimulate various forms of production. They should not be regarded as unmixed blessings, for many of them have a narrow margin between the limits of safe usage and the production of toxic effects ; the greatest care must be exercised in their uniform incorporation in the food. It is impossible in this short reference adequately to cover all aspects of additives from the point of view of toxicology, undesirable side effects, margins of safety, residues in animal products and carcases, legislation and so on. In recent years a vast amount of research has gone into the production and use of additives, and it is evident that we are only at the beginning of an era of additive supplementation of foodstuffs. There are tremendous possibilities in the use of medicaments added to food for the control of disease in animals, for health promotion, and for stimulating productivity. At the same time it must be appreciated that additives can be powerful forces for evil as well as good, but without doubt, their uses in the future will continue to expand.

Water. At every stage in the development of the animal, water is the most abundant ingredient in the make-up of its body, ranging down from 80 to 90 per cent in the fertilised ovum to 70–80 per cent at birth and then to a fairly steady 50–60 per cent in the full-grown, lean animal. Even in a prime fat animal there will still be some 40 per cent of water, so that a 10-cwt. fat bullock will contain 450–550 lb. (45–55 gallons) of water in its body substance ; despite the steady loss of water in the excreta and by evaporation the supply must be kept up at this level if the animal is to continue healthy and active.

In computing water requirements the water contained in the food must be taken into account, and this in the case of succulents may cover a considerable part, or even the whole, of the animal's water needs. These needs vary widely with changing conditions, and are best met by the provision of free access to water. Excessive consumption of water, with ultimate deleterious effects, is only likely to arise where the animal is forced to it, e.g. by heavy root feeding. The water requirements of farm livestock are set out on page 99.

In adult animals with free access to drinking water there is usually a rough correlation between the amount of water consumed in food and drink and the total dry matter consumed in food. For most farm animals the ratio is usually in the region of 3–4 lb. of water to 1 lb. of dry matter, the proportion of water tending to rise with the fibre content (and also the protein content) of the food. The greater water consumption in hot than in cold weather is also familiar.

In young growing animals the water-requirement in proportion to live-weight steadily falls as growth progresses. Thus the suckling calf requires about twice as much water per 1 lb. of live-weight as the full-grown steer. Shortage of water is thus especially serious with the young animal, and even a moderate shortage may cause serious retardation in the case of the quicker-growing species, such as pigs and chickens. In milk-production and egg-production, where large amounts of watery products are removed from the body, the provision of an adequate water-supply is obviously one of the master keys to high production.

THE FEEDING-STUFFS

For the successful and economical construction of rations for farm animals, some knowledge is required of the composition and digestibilities of feeding-stuffs and of their suitability for each class of animal. The reader will find data for the average composition, digestibility and nutritive value of feeding-stuffs in readily available tables. Here it is proposed to discuss only the general nutritive and dietetic qualities of feeding-stuffs and to indicate the various factors responsible for variations in composition and digestibility.

THE CLASSIFICATION OF FEEDING-STUFFS

Comparison and tabulation are, of course, facilitated by classification and it so happens that animal feeding-stuffs fall conveniently into four main groups based on the characteristic qualities of (1) succulence, (2) richness in fibre or (3) high concentration of digestible nutrients. This method of grouping brings together feeding-stuffs with similar dietetic properties, and has the practical advantage of facilitating the selection and replacement of one food by another in animal rations. Sub-division of these major groups can be made in a variety of ways in accordance with some other property, such as the origin of the feeding-stuff or a particular nutritive quality like high protein content. No rigid classification is possible since some feeding-stuffs may have characteristics which would justify their inclusion in more than one group. The particular choice of group is, then, just a matter of opinion.

I. Dry Roughages or Coarse Fodders

(1) Hay—grass, cereal and legume hays.
(2) Straw—cereal straws, pea and bean straws.

II. Succulent Foods

Roots and tubers—mangels, swedes, turnips, carrots, potatoes, etc.

III. Green Forages

Immature crops of grass, clovers, lucerne, sainfoin, vetches, kale, cabbage, rape, maize; silage, beet tops, etc.

IV. Concentrated Foods

(1) Cereal grains and their by-products—oats, barley, wheat, maize, rye: weatings, bran, etc.
(2) Leguminous seeds—beans and peas.
(3) Oil seeds—linseed, sunflower seed.
(4) Oil cakes and meals—ground-nut cake, linseed cake, soya-bean meal, etc.
(5) Animal products—meat and bone meal, fish meal, etc.

THE DRY ROUGHAGES

The dry roughages are characterised by a high content of crude fibre (23–43 per cent) and by the physical quality of bulkiness. On these accounts, the dry roughages are best suited to form part of the maintenance rations of cattle, sheep, goats and horses; they are useless for feeding to pigs and poultry.

Hay. Hay, made by the sun-drying of green, but nearly mature, grasses, clovers and cereals, is the traditional form in which these crops are conserved for winter feeding. Unlike roots and concentrates, the hays are usually good sources of calcium, and they contain important amounts of potassium, magnesium and other minerals. On the other hand, unless obtained in good, green condition, the hays tend to be rather poor and frequently inadequate sources of carotene and vitamin E, although they may contain significant amounts of vitamin D for animals kept indoors.

The hays, and to a less extent the straws, are extremely variable in composition and digestibility. Even where concentrates are carefully rationed, the influence of hay quality on the milk output from a herd of dairy cows can become sharply manifest when the winter milk yield following a good hay harvest is compared with that following a poor haymaking season. The crude protein content of meadow hay varies from 4 to 13 per cent, the fibre content from 23 to 35 per cent and the starch equivalent from 18 to 40 per cent.

The poorest hays are certainly no better than oat straw, and it is scarcely possible for a cow to eat enough poor hay to maintain bodyweight and condition. On the other hand, the best hays may be fed, if it is desired, as the sole food for maintenance and the production of two gallons of milk. The difference between poor and good hay is actually greater than it would appear from their digestibilities, for it seems that the digestible nutrients and minerals in good hay can be utilised more efficiently than those in poor hay. Moreover, the difference in palatability is such that cows will eat a ration of good hay in less than three-quarters of the time taken to consume the same weight of poor hay. Most well-made meadow hays fall within somewhat narrower limits of composition than those given above, the crude protein content ranging from 8 to 10 per cent, the digestible protein content from 3 to 6 per cent and the starch equivalent from 28 to 35 per cent. The differences in protein content are important. At the lower level of protein, the ratio of starch equivalent to digestible protein is about 10 to 1 and there is no surplus of protein relative to energy requirements for maintenance. At the higher level of 10 per cent of crude protein, the starch equivalent-protein digestible ratio is about 7 to 1 and there is enough protein in a full maintenance ration of hay to make it necessary to feed only cereals or even mangels for the first gallon of milk.

Factors Influencing the Quality of Hay. Recognition of this variability in composition of even " well-gotten " meadow hay should guard the reader against a common tendency to overestimate the feeding value of such hay. It has to be remembered that the getting of hay in good weather satisfies only one essential for the production of hay of high feeding value (see pp. 337–8). Four factors are mainly responsible for variations in the nutritive quality of hay.

(1) The Stage of Growth or the degree of maturity of the herbage at cutting. This is a most important factor. For convenience in the making of hay, grasses must be allowed to reach the flowering stage, but as cutting is delayed beyond this point, there is an increasing deterioration in the protein content and digestibility of the crop. Lignification of the stems increases rapidly and the leaves die as their nutrients are transferred to the seeds. The dropping out of the seeds means the loss of material approaching oats in feeding value.

(2) The Botanical Composition of the Herbage. The superior grasses, e.g. perennial rye grass, cocksfoot and timothy, are of higher feeding value than Yorkshire fog, crested dogstail and the bromes and bent grasses of acid meadows. The protein and calcium contents of the hay tend to increase with the proportion of clovers.

(3) The Weather Conditions at the Time of Making. Rain and dull cool weather are unfavourable to haymaking. Loss of digestible carbohydrate through respiration is increased by slow drying ; moulding is very apt to occur and rain leaches out soluble constituents from partially made hay. All these losses fall on the more digestible nutrients. Excessively hot and sunny weather can also be detrimental since it is then easy to overcure hay which becomes too dry, harsh and brittle, while loss of carotene may be almost complete.

(4) The Method of Making. Leaves dry out more readily than the stems. This is particularly true of the clovers, and when curing takes place in the swath, the leaves tend to become overdried, brittle and easily broken off during handling. Since the leaves are richer in protein and other nutrients than the stems, the loss of leaf inevitably means loss of feeding value. Drying in windrow and cock reduces the difference in the rates of drying out of leaves and stems and permits a leafier hay to be made. At the same time, the crop is less exposed to the bleaching action of the sun and the leaching action of rain. Hay which has been "barn-dried" (see p. 341) is usually of better quality than hay made by traditional methods.

Types of Hay. Hay taken from short-term leys is characterised by consisting mainly of the superior grasses and clovers and of far fewer species of herbage plants than meadow hay. It appears to be equally variable in composition and the average sample is no higher in feeding value. It is usually a harder hay.

"Seeds" hay is made from a one-year ley mixture of grasses and clovers grown on arable land, with rye grass and red clover usually predominating. Potentially, it is capable of being much richer in protein and calcium than meadow hay, since a high proportion of clover is sown and intended to be present in the mixture. In practice, however, the proportion of clover is very variable. Moreover, much clover leaf is lost in making and "seeds" hay is therefore seldom very much richer in protein than meadow hay. Its digestibility and starch equivalent tend to be slightly lower than those of meadow hay owing to the presence of a higher proportion of clover stem.

In spite of their greater content of protein, clover, lucerne and sainfoin hays tend to have energy values or starch equivalents which are on the average appreciably lower than those of meadow hay. This is because lignification and the development of woody stems proceeds very rapidly when flowering commences in these crops. Hence, if good-quality hay is to be obtained, cutting should preferably start as flowering begins and it should not be delayed beyond the point where most of the crop has come into flower. Since the great value of these crops lies in the leaves, which may contain 25 per cent or more of protein in the dry matter, it is worth while spending extra care in the making. The differential rate of drying between leaves and stems is far greater in the case of clover, lucerne and sainfoin than it is for the grasses. The dry leaves are very easily shattered. The crop should therefore not be left to lie long after cutting but should be put into windrow or cock or perhaps preferably made on tripods.

Heavy yields of hay may be obtained from oat and pea or oat and tare mixtures grown on arable land (see p. 288). The protein content and digestibility, like those of other hays, largely depend on the proportion of legume and the stage of growth at which the crop is cut. Mowing should not be delayed beyond the point where the pea or vetch pods have just formed.

Straw. Compared with the hays, the straws are markedly inferior in feeding value since they are more fibrous, less digestible and considerably poorer in protein, minerals and vitamins. In fact, no kind of straw from which ripened seed has been threshed is capable of supporting any class of animal without some other food. The full-grown bullock or barren cow may subsist for a comparatively long time, if need be, on good oat straw because it has no urgent nutrient requirements for growth and production, but it cannot maintain body-weight and condition indefinitely on such food.

Straw can therefore be fed most usefully to strong stores, beef breeding cattle, slowly fattening bullocks and other cattle in need of roughage to fill capacious digestive tracts. It can replace only strictly limited amounts of hay in the rations of more productive animals such as young growing cattle, milking cows and cattle in forward condition of fattening.

Such replacement of hay by straw is possible on the understanding that there is an increased need for concentrates or other food richer in protein and minerals. This fact is commonly overlooked when straw is fed during the late winter months to bulling heifers.

The feeding value of straw varies with the species and variety of cereal or grain crop ; with the degree of maturity of the crop and the weather conditions at harvest ; and with the soil and climatic conditions under which the crop is grown. It is advisable to feed straw in the long state, allowing the animal to select the more palatable and digestible portions and to reject the woody butt ends. Chaffing and grinding may save some energy of mastication, but the animal is forced at the same time to consume more non-digestible material and to reduce correspondingly its intake of useful food.

Oat straw is undoubtedly the softest and most digestible of the straws. This may be attributed in part at least to the fact that the oat crop is usually cut before it is fully ripe. This is particularly the practice in Scotland, northern England and on hill farms where the varieties of oats grown are best suited to the shorter season and the cooler and moister climatic conditions, and where there is every inducement to harvest the crop at the earliest possible moment. In some districts of Scotland and northern England it is consequently possible to fatten cattle on oat straw and turnips, whereas this is impossible in the drier and warmer south where the oat crop is harvested in a more mature state.

None of the straws is really suitable for feeding to sheep, but oat straw is the best for sheep to pick over when hay and other winter food is scarce. Horses digest straw much less efficiently than cattle, and only good oat straw is suitable for feeding to these animals. Long oat straw may be fed to horses which are not working hard, and it is the custom to mix oat straw chaff (2–4 lb.) with oats and other concentrates to ensure adequate mastication.

Barley straw is somewhat inferior to oat straw because the barley crop is almost always allowed to stand until it is fully mature before being cut and harvested. The feeding value of the straw, however, is often enhanced by the presence of clover from an undersown "seeds" crop, and the mixture may then be as good as, or even better than, straight oat straw. Barley straw is best fed low down in order to avoid the danger of the awns entering and lacerating the eyes of cattle.

Wheat and rye straws are undoubtedly the least digestible of the cereal straws. They are more fibrous, more lignified and more silicaceous. (The ash of straws consists very largely of silica.) Very seldom is the attempt made to feed rye straw to farm animals and the main use for both straws is for bedding, thatching and packing. If wheat straw has to be fed, it is best reserved for the older and low-producing cattle. It is useless for horses, which can digest only about 20 per cent of the organic matter and actually spend more energy during the digestion process than is available from the straw.

Pea and bean straws are richer in protein and calcium than cereal straws but the stems are less digestible : bean straw, in particular, can be very fibrous, woody, unpalatable and costive. It is not easy to harvest these straws in good condition, and they are apt to become mouldy during storage and therefore unsuitable for feeding. Good pea and bean straws may be fed to store cattle, bullocks and low-yielding cows, but the allowance should preferably not exceed one-third of the total dry fodder intake. It is often the practice to chaff these straws, but they are better fed in the long condition so that cattle can pick out the pods and the more nutritious tops and leaves.

Linseed, vetch, rape and clover straws have little or no feeding value.

Chaff and cavings are separated during the threshing of grain. Their feeding value can be higher than that of the corresponding straw. Cavings consist of pales from the ears, broken stems and leaves and other material from the sheaves. A high proportion of clover leaf can enhance the feeding value but this may be counteracted by the presence of soil, mould and unpalatable weed seeds. Chaff consists of glumes, broken awns and leaves and the feeding value largely depends upon the proportion of leaf. Both chaff and cavings are light, dry materials which are best fed by mixing and moistening with pulped roots. Barley chaff may contain useful amounts of clover leaf, but the presence of broken awns reduces the value of the chaff, at least in the dry state, since the awns are liable to penetrate the mucous membrane of the mouth and thereby facilitate the entry of the actinomycosis organism.

Linseed chaff consists of husk from the broken seed bolls, broken leaves and a variable amount of unseparated seeds, particularly small, unripe seeds. The feeding value of the chaff depends almost entirely on the proportion of leaf and seed present. At its best, linseed chaff is a very fibrous material and, if it must be fed, then it should be given only in small amounts.

Oat Chaff. It has long been the custom in some localities to chaff oat sheaves without threshing out the grain. The product is therefore a mixture of oat grains and oat straw chaff. Its feeding value depends upon the proportion of oats to straw as well as upon the factors affecting the quality of straw and grain. The proportion of straw may run from about 50–70 per cent or more. Allowing for the chaffed state of the straw, the starch equivalent of the mixture may be taken to be somewhere between 35 and 45; the energy value of chaffed oat sheaves is therefore about 20–40 per cent higher than that of hay fed in the long state, but hardly better if the hay is also chaffed. The protein equivalent may be estimated to be between 3 and 4 per cent, which is about the range for poor to medium hay. From the nutritional standpoint, the feeding of chaffed oat sheaves is to be deprecated since the animal is given no opportunity to reject the less nutritious butt ends of the straw. On the other hand, the cost of chaffing is considerably less than that of threshing, and where large amounts of oat straw have to be fed, the practice may have some economic justification.

SUCCULENT FOODS

The succulent foods are characterised by a high content of water, ranging from about 70 to 93 per cent. They possess mildly laxative properties and, usually, they are highly digestible. These qualities make the succulent foods nutritionally and dietetically valuable for all animals, particularly when on winter diets of rather costive, dry fodders: they are especially valuable for high-producing or pregnant animals or for those that are ill. Apart from their feeding value, roots and green forages are usefully grown as cleaning or weed-smothering crops.

All the succulent foods have a low content of oil, protein and fibre, and negligible amounts of carotene (except carrots) and calcium.

Wet sugar beet pulp, wet brewers' and distillers' grains, wet maize gluten meal, swill, liquid skimmed milk and whey are also succulent foods, but these by-products have not the same dietetic properties as the natural succulent foods.

Roots and Tubers. The roots and tubers are succulent carbohydrate foods.

At similar dry matter contents, mangels and turnips have about three-quarters of the starch equivalent of oats and three-fifths of the starch equivalent of barley. In spite of being highly digestible (90 per cent), the carbohydrates in roots seem to be utilised less efficiently than the predominantly starchy carbohydrates of cereals. Soluble sugars, sucrose, fructose and glucose form about one-half to two-thirds of the carbohydrates in roots, the rest being easily fermentable pectins and cellulose. On the other hand, the main carbohydrate in potatoes is starch, which is easily digested by all animals without the aid of bacteria. This may largely explain why potatoes are a better carbohydrate food than roots for pigs and poultry. The higher dry-matter content is also a factor, but potatoes are still a better food for cattle than sugar beet roots with almost the same dry-matter content.

The starch equivalent of roots increases with the dry-matter content and, for each kind of root, the dry-matter content is known to vary with the variety, soil, size of root, manurial treatment and season. Red soils seem to favour the production of roots with higher dry-matter contents than those grown on dark soils. Large roots tend to be more watery than small roots. The crude protein fraction in roots and tubers consists largely of " amides " and of only a small proportion of " true " protein. The digestible protein contents are therefore very low. The ratio of starch equivalent to digestible crude protein in mangels is close to the required ratio of 10 to 1 for maintenance foods. On the other hand, sugar beet pulp, kohl rabi, carrots, and especially potatoes and artichokes, are relatively deficient in digestible protein even for maintenance rations.

Mangels. The dry-matter content of mangels ranges from about 9 to 14 per cent. No variety or strain of mangel can be safely fed until after Christmas, or sometimes not until the end of January. Unripe mangels contain nitrates and these and possibly other constituents can cause severe scouring in cattle and sheep. The mangel crop is therefore lifted and stored in clamps to ripen as well as to keep until needed in late winter. During the ripening process the nitrates are converted to " amides ", and the latter in turn are partly converted to true protein. Mangels do not impart a taint to milk and, on this account, they are more useful than swedes and turnips for feeding to milking cows.

In the past, huge quantities of 1 cwt. or more daily of mangels and other roots were fed to dairy and fattening cattle. It was then necessary to pulp and feed the roots with chaff. Nowadays, cows are given more reasonable amounts of 20–40 lb. of mangels per head per day. This change of practice has been brought about by several factors, but mainly the high cost of growing and feeding roots, possibly assisted by the powerfully made suggestion that roots are too bulky for dairy cows. Only cleaning and no pulping or slicing is necessary when feeding the above quantities of mangels. About 30 lb. is the maximum amount that can be comfortably consumed in one meal by Shorthorn cows. Sheep are not folded on mangels as they can be on swedes and turnips. Mangels are usually carted from the clamp and fed to sheep on grass or in folds on arable land in late winter, the maximum amount per adult sheep being about 14 lb. per day. Mangels may be fed in small amounts to calves over three months of age, to hard-working as well as idle horses, to sows and even to fattening pigs. For the latter, the maximum amount should be about 5 lb. of fingered roots per day, replacing about ½ lb. of barley meal. Double this quantity may be fed to pregnant sows. Split mangels are also usefully fed to fowls kept in fold units or intensive houses. The roots help to keep the birds feeding and also provide useful bulky food normally supplied by grass when birds are on free range.

Swedes are an excellent succulent food for all classes of stock. The dry-matter content ranges from about 10 to 13 per cent according to variety and soil conditions. Newly pulled swedes can have severe scouring properties, but their laxative nature becomes milder after a period in the clamp. In some southern districts, swedes may be left in the ground until late winter and then folded with sheep.

White-fleshed turnips have the lowest dry-matter content (7–8 per cent) of all roots. The yellow-fleshed varieties have dry-matter contents ranging from 8 to 10·5 per cent. Turnips are quickly grown and are useful for folded sheep in the autumn. They are sometimes sown in mixture with rape as a pioneer crop on very poor ploughed-out grassland before it is sown down with better grasses.

Kohl rabi can be used as a feeding crop from August to March. The roots may be fed whole to cattle, sheep and horses. Since kohl rabi does not taint milk, it can provide a valuable succulent food for dairy cows during late summer droughts. The crop can be folded by breeding ewes and fattening lambs.

Carrots are grown primarily for human consumption but unmarketable and surplus carrots can be fed to, and are relished by, all classes of stock. The carotene content of the roots is high and carrots are therefore most valuable when the rest of the diet is poor in carotene. Hence they are especially useful for helping to maintain health and good coat condition in horses kept continuously on dry rations in town stables and elsewhere.

Potatoes are an extremely useful carbohydrate food for farm livestock. They must, however, be reasonably clean and free from sprouts which are apt to contain toxic amounts of the alkaloid solanine. The dry-matter content of potatoes averages about 24 per cent and it consists predominantly of the highly digestible carbohydrate, starch. For pigs and poultry, potatoes should be steamed or boiled in order to obtain most efficient and economical utilisation, although a few raw potatoes may be fed to all but young pigs. Cooking not only improves palatability, but it bursts the starch grains and renders the starch more accessible to the digestive juices. About 4 lb. of potatoes may be taken, after cooking, as equal to 1 lb. of barley meal in energy value. Pigs may be given cooked potatoes in quantities running up to a maximum of 16 lb. per head per day according to the age and the purpose for which the pigs are kept. For poultry, cooked potatoes may comfortably form 50 per cent of the total ration, but the proportion may be increased to 80 per cent with proper choice of supplementary foods. Mature cows can be safely given 20 lb. of raw tubers per head per day without causing scouring or blowing. About 1 lb. of raw potatoes is equal to 2 lb. of mangels. Mature fattening cattle can be given 40 lb. and even 80 lb. of raw potatoes per head per day provided care is taken to introduce them gradually into the ration. Furthermore, greedy feeders in yards must not be allowed to get too large a share at any one meal owing to the risk of bloat. Raw potatoes are unsuitable for young stock or pregnant animals.

Fodder Beet. The high dry matter (18–21 per cent) types are almost indistinguishable from sugar beets, while those with 15–18 per cent dry matter may resemble mangels. Fodder beet, sliced or fingered, can be fed to fattening pigs up to a maximum of about 20 lb. daily for a pig of 220–230 lb. live weight, each 4–6 lb. of fodder beet (18 per cent dry matter) replacing 1 lb. of cereals. About 50–60 lb. of medium dry matter fodder beet can be fed daily to dairy cows.

Sugar Beet Pulp. Both wet and dried sugar beet pulp are valuable feeding-stuffs in the sugar beet growing areas where the acreage of other roots is necessarily reduced. Transport costs limit the use of the wet pulp mainly to farms within reasonable distance from the factory. Furthermore, the product is very liable to go sour when exposed to air, but it can be safely ensiled in pits until required for feeding. It can be fed in about the same amounts as mangels. Dried sugar beet pulp may be fed as a substitute for roots, or as part of the concentrate ration. About 1 lb. of the dried pulp is equal to about 8 lb. of mangels or 1 lb. of oats. The maximum amount for dairy cows is 8 lb. per day, but fattening cattle may be given 10–12 lb. per head per day.

Dried sugar beet pulp swells considerably when moistened with water and so the larger quantities for cattle are often soaked before feeding. This treatment is specially necessary when sugar beet pulp is given to horses, since it would be dangerous to allow the swelling of the pulp to take place in a full stomach. Half the corn ration of horses has been replaced by a mixture of equal parts of dried beet pulp and molassed beet pulp with apparently satisfactory results, but beet pulp is a rather bulky food for hard-working horses.

Dried beet pulp can be fed in limited amounts to pigs. A considerable proportion of the fibre in beet pulp is broken down in the large intestine and cæcum of the pig, but the product is still too bulky and its digestible carbohydrates rather inefficiently utilised to permit sugar beet pulp to be freely fed to pigs. About 2 lb. per head per day is the maximum amount for non-lactating sows and about 1 lb. per head per day for fattening pigs. The food is best omitted from the rations of very young pigs and it is unsuitable for feeding to poultry. Molassed beet pulp is more palatable, but otherwise its feeding value is very similar to that of the plain dried pulp.

Beet molasses is the syrupy residue left after crystallisation of the sugar from beet juice. Its water content varies from about 20 to 30 per cent : at an average moisture content of 25 per cent, the syrup contains 66 per cent of soluble sugars, about 5 per cent of ash and 3·5 per cent of crude protein which is of very little feeding value, the main nitrogenous constituent being betaine. The ash consists mainly of potash, which is partly responsible for the laxative properties of molasses. The product is useful for enhancing the palatability of feeding-stuffs for cattle. It is largely fed to animals for this reason rather than as a straight food. It is a useful laxative and is used in the treatment of cases of acetonæmia in dairy cows. Its sticky binding properties make molasses a useful ingredient of compound cattle " cubes " and pig " nuts ".

GREEN FORAGES

Under the heading of green forages must be considered the grasses and young cereals, certain legumes and such brassicas as kale, rape and cabbage which are customarily grazed or cut for feeding. In contrast with the succulent fodders, the green forages are characterised by relatively high protein contents, particularly in the early stages of growth, and the fact that they are all good sources of β carotene, the precursor of Vitamin A.

Grass and Clover. The grass crop is pre-eminent among green forages on farms of the British Isles. Although pure stands of grass are grown, it is more usual to find mixtures of grass and clover or other legumes forming the basis of our grassland farming.

The major seasonal changes in the nutritive value of grassland herbage are those associated with maturation of the plant. As physiological age increases, there is a rapid decline in protein content, due mainly to a fall in the proportion of leaf present, and a marked fall in energy value caused by increased development of fibre. It is this change in the proportion of leaf to stem as the grass plant develops which holds the key to its nutritive value.

Leguminous plants also decline in feeding value with age. However, with these plants, the protein content does not fall so markedly with the onset of maturity as in the grasses, although the fibre tends to rise more quickly, with an accompanying fall in their digestibility and energy value.

Although maturation in plants is a continuous process, it is possible by dividing it into three arbitrary stages, to estimate the feeding value of the herbage from visual observation.

(*a*) *Leafy or early bud stage.* In the grasses the leafy stage is marked by a complete absence of flower heads or of the stem associated with the flowering parts of the plant. The corresponding stage in leguminous plants is the early bud stage, when there are a few flower buds forming on the plants but none is in full flower. At this stage of growth, the plant is rich in protein and energy, with a close ratio of digestible protein to starch equivalent (about 1 to 5) making it particularly suitable as a productive food for milk.

(*b*) *Early flowering stage.* At this phase of development of the plant, the early grasses are in ear, pollen is blowing about and the stem is very noticeable. In leguminous plants the flowers are forming on the lower parts of the plant though no seed should be present in the early flowers. The protein content and the digestibility have both fallen by this time, and the ratio of digestible protein to starch equivalent for mixed herbage is now wider (about 1 to 7 or 8). With pure leguminous crops the ratio is more narrow because the relatively high proportion of protein and greater development of fibre give a more marked fall in the starch equivalent value.

(*c*) *Full flower stage.* By this time the grass plant has almost completed its growth cycle except for the formation of seed. Lignification is now proceeding fast, nutrients are being transferred to the seed or roots, and there is an obvious increase in the proportion of stem to leaf, resulting in a steep fall in both the digestibility and the feeding value of the plant. There is a similar loss of value in leguminous plants. The ratio of digestible protein to starch equivalent value has widened still further, and in all except pure leguminous crops, will now be about 1 to 10, making it only suitable as a maintenance food.

A guide to the relationship between stage of growth, chemical composition and nutritive value of both grass and clover is given in the table on page 551.

Table 5

RELATIONSHIP BETWEEN STAGE OF GROWTH, COMPOSITION AND NUTRITIVE VALUE OF GRASSES AND CLOVERS

Crop.	Per cent in the dry matter. Crude Protein.	Crude Fibre.	Total Ash.	Calculated. Starch Equivalent.	Digestible Crude Protein.
Grass					
Very leafy	23·5	17·0	10·0	75	18·9
Leafy	15·5	18·8	8·2	74	11·2
Early flowering . .	13·5	23·1	8·1	66	9·3
Full flower . . .	9·2	30·4	7·2	53	5·2
Red Clover					
Pre-bud	25·3	18·2	10·6	63	21·2
Early bud	20·7	23·9	8·8	58	16·6
Early flowering . .	18·0	27·5	8·5	54	13·9

The starch equivalent and digestible crude protein values in the above tables were calculated from work carried out in the Netherlands.

The mineral content of a pasture is influenced by the species present ; generally speaking, the herbs and legumes are better sources of mineral matter, particularly calcium, than the grasses. At the young and leafy stage of growth, the mineral content of most species is relatively high, but falls with the onset of maturity. In mixed pastures, this decline with maturation may be overshadowed by a change in the botanical composition of the sward, giving an apparent increase in mineral matter. This is particularly so where the proportion of legumes in the sward increases as the sward matures ; and is commonly found in practice where the aftermath cuts have a greater preponderance of clover than the earlier ones.

The practice of accumulating pasture growth during the late summer and autumn to provide grazing (Foggage) for cattle and sheep in the winter, and hence extending the effective grazing season, is of long standing in certain parts of the British Isles. Recent developments in grassland management, together with the use of suitably improved strains of grasses and adequate dressings of compound fertilisers, have improved the quality of the herbage available for grazing in the winter period. Suitable grass strains for this purpose should exhibit a high resistance both to frost damage and also to rotting under the cold wet climatic conditions often prevailing in early winter. Such pastures, which have been rested from late July until early December, should have a good proportion of green leaf present in the mid-winter period ; the feeding value of this herbage may resemble that of summer grass at the flowering stage of growth.

Cereals. The sowing of autumn rye to provide early spring grazing for cattle and sheep has become another popular way of extending the grazing season in this country. This crop can advance the start of the grazing season by as much as 4 to 6 weeks, and since it is utilised at the young and leafy stage of growth, its feeding value will be similar to that of grass at a corresponding age.

In the arable districts advantage is sometimes taken to graze off the excess growth of winter-proud cereals during the early spring period. This, too, provides a highly nutritious food similar to that of young and leafy grass, but the grazing is only an incidental by-product of grain production.

Leguminous Plants. Apart from the clovers which have been already mentioned, a number of other leguminous plants require mention.

Lucerne. Lucerne has been found to have a relatively lower nutritive value, under conditions in Great Britain, than properly managed grassland herbage. This is due mainly to the more rapid lignification in the stem of the lucerne plant, causing a fall in both the digestibility and the starch equivalent value, when compared with grass at a similar stage of growth.

Sainfoin. Sainfoin is a crop confined to a few areas in this country. It is a typical legume in respect of its richness in protein and calcium, but does not tend to become unduly fibrous. It compares very favourably with lucerne in nutritive value. For certain areas where potash deficiency is likely to have a serious effect on the growth of lucerne, it may be preferred as a drought-resistant leguminous crop.

Maize. Maize is always used at a relatively advanced stage of growth, and hence the product is normally low in protein. The leaves and stem change relatively little during the later stages of growth, while the developing ear, containing a high proportion of easily digested carbohydrates, rapidly increases in feeding value. Thus, unlike most fodder crops, as the maize crop matures the increasing contribution made by the ears results in improved feeding value. The optimum stage of growth for harvesting is when the grains in the ear are in the soft dough stage. Maize, at this stage of growth, has been found to have a starch equivalent between 45 and 50, and a digestible protein of about 5 per cent, in the dry matter.

Brassicas. Certain species of Brassicae are very important indeed as green forage crops: their cultivation has been described in Chapter X.

Kale. There are two main groups of kale, namely the Marrow-stem and the Thousand-head. The Marrow-stem variety has a fleshy stem of varying thickness, and is less frost resistant than the harder stemmed Thousand-head variety. In both there is a significant difference between the composition of the leaf and the stem and hence the proportion of each present is very much reflected in the composition of the whole plant. Kale leaves, like those of the legumes, are rich in protein and minerals, particularly calcium, but the stems, while being higher in fibre than the leaves, are less fibrous than the stems of leguminous plants. This means that kale not only has the high protein and mineral status as found in legume plants, but, also, a relatively high energy value. The difference between the feeding value of the Marrow-stem variety and the Thousand-head variety is small when the two are grown under similar conditions. Normally both varieties have a starch equivalent of 60–65 in the dry material and a digestible protein averaging 10% ; but the digestible protein content of any particular crop is very dependent on the proportion of leaf to stem present.

When kale is grazed, the leaf and the top third of the stem are almost invariably eaten, but the remainder of the stem is rejected in varying degrees. This lower part of the stem has a higher content of dry matter and crude fibre but a lower content of protein, calcium and phosphorus. Thus when utilisation is incomplete, the least nutritious portion of the plant is rejected. Since the rejected portion has a high dry matter content relative to the whole plant, yields which are quoted for the crop without due regard to the probable degree of utilisation may give an exaggerated impression of the quantity of nutrients which it supplies.

Rape. Rape may be classified into one of three main groups, namely the giant rape, broad-leaved Essex rape, and the rape-type kale. The differences between these groups lie mainly in their height of growth and size of leaf. As with kale, there is no real difference in feeding value between the groups grown under similar conditions but variations in the protein content of plants are brought about by changes in the proportion of leaf to stem. Recent findings suggest that the feeding values of kale and rape are similar.

Cattle Cabbage. Cattle cabbage is grown on a limited scale as an alternative to kale, particularly where the crop cannot be grazed and has to be cut and carted. Since the stem in this crop makes up only a small proportion of the total plant, the composition of cabbage is less affected by the proportions of leaf and stem present. There are, however, marked differences between the inner and outer leaves which explain the differences between the drum-head and the open-leaved varieties. The former variety, which contains a high proportion of heart leaves, has a higher content of protein and soluble carbohydrates in its dry matter but a lower content of fibre and calcium than the open-leaved varieties. These differences are overshadowed in practice by the significantly higher dry matter content of the open-leaved varieties. In general, the composition and feeding value of the open-leaved varieties of cabbage closely resemble kale, whilst that of the drum-head varieties have only about 60–70 per cent of the feeding value of kale.

Sugar Beet Tops. Sugar beet tops consist of the leaves of the plant and also the upper part, or crown, of the root. They thus combine the properties both of a green fodder and of succulents. In the fresh state the tops have a composition and feeding value slightly inferior to those of kale.

CONCENTRATED FOODS

Under this heading it is necessary to consider the cereal grains and cereal by-products, leguminous seeds, oil cakes and extracted meals animal and marine by-products and one or two miscellaneous items.

Cereal Grains and their By-products. The cereals are chiefly carbohydrate with 8–15 per cent protein and a poor Ca/P ratio.

Wheat. Wheat may be fed to pigs and poultry, although there is always a danger that if ground too finely it will form a pasty mass in the mouth. Consequently, if wheat is fed to pigs (or to cattle) it should be crushed or only coarsely ground, and mixed with other meals. Wheat is said to be liable to cause skin troubles and laminitis when fed to horses.

Before considering wheat by-products, it will be as well to look at the structure of the wheat grain. This consists of an endosperm containing starch and gluten : around this comes the aleurone layer, which is rich in protein : enclosing the grain is the outer coat or pericarp, consisting chiefly of fibre and ash. In addition, there is also the wheat germ, which amounts to approximately 2 per cent of the grain. The process of milling is primarily designed to obtain the endosperm which we know as flour ; various types of by-product, or " offals ", arise, which consist of the pericarp and aleurone layer with varying degrees of endosperm. These offals consist of *bran*, and various other products which used to be grouped broadly into three main categories : (1) pollards ; (2) coarse middlings or sharps ; (3) fine middlings or thirds. Wheat offals, other than bran, are now marketed as *weatings*, with a guarantee of not more than 6 per cent fibre. The differences between the various grades in fibre content and minerals are shown in the published tables.

Bran is a palatable feeding-stuff, somewhat laxative and capable of " opening up " a heavy ration ; because of its content of protein and fibre it is much more suitable for inclusion in rations for breeding, growing, milking or working animals than it is for fattening stock. Like wheat itself, and the other by-products, it has a low Ca/P ratio. Weatings are very popular for both pigs and poultry and may also be given to cows.

Barley. Barley is essentially a fattening food, and if used for the production of milk and eggs must be balanced with appropriate amounts of protein and minerals. Barley meal has been recognised for a long time as a splendid feeding-stuff and it is normally used extensively in rations for fattening pigs.

In the brewing of beer, barley yields a number of useful by-products. After the grain has germinated during the process of malting, the root and shoot are removed, and this material is known as *malt culms*. Malt culms should always be soaked before feeding and can be fed to dairy cows, horses and sheep. The malt is steeped in water to extract the sugar, and after the sugary solution—the so-called wort—has been run off, *wet brewers' grains* remain. These consist chiefly of protein and fibre, the starch having been lost during the malting and steeping processes. Wet brewers' grains may be fed to dairy cows, but excess is liable to cause scouring. This feeding-stuff must be used immediately or else ensiled with salt in pits, since it turns sour very readily on keeping. It is too expensive to transport very far, but *dried brewers' grains* are also available ; these are useful for milk production and can also be used for fattening cattle and sheep. They are too fibrous for pigs. The distilleries also provide by-products of a similar nature to those just mentioned and the pearl barley industry gives rise to small quantities of *barley feed* which is useful for pigs.

Oats. A good sample of oats should be bright in appearance, and the higher the bushel weight the lower will be the percentage of husk. Oats have a better Ca/P ratio than other cereals, but are also richer in fibre. They are the favourite cereal for horses, to which they can be fed whole; it is usual to crush them when feeding to other stock. Dairy cows, fattening bullocks and sheep can all be given oats, and despite their fibre content they can be used fairly extensively in pig rations, although the husks are sometimes sieved out before feeding to young pigs. Oats are also given to poultry but *Sussex ground oats* are more popular for this class of stock. In oatmeal milling districts such by-products as *meal seeds*, *scree dust* and *oat-dust* are also available for pigs.

Rye. The previously mentioned cereals are extensively grown in these islands, but rye is a very minor crop, although it is the chief cereal of northern Europe. It is not popular as a feeding-stuff with farmers, neither is it relished by stock, but if used it can be considered as being roughly equivalent to wheat.

Maize. This cereal is not grown for grain in this country except on a very minor scale, but large quantities are imported. Its composition makes it suitable for fattening rather than for other productive purposes, because it has a high carbohydrate and low fibre content while the protein is poor in quantity and quality and the grain is deficient in minerals. The yellow varieties of maize contain cryptoxanthine, a precursor of vitamin A, and are given to laying hens; the white varieties containing no carotenoid pigment are sometimes fed to fattening birds in order to maintain a white flesh. Maize should be cracked or kibbled for dairy cows, but very often it is ground to give maize meal.

Maize meal is of two types, the one having the maize germ left in, the other having this removed and hence being lower in oil and less likely to go rancid. By treating maize with steam and then rolling and drying, *flaked maize* is produced, which, because of its lower oil content, is favoured by pig feeders, although the production of a soft oily carcass should not occur if maize is used with discretion. Flaked maize is also favoured by other stock feeders.

During the manufacture of cornflour and starch from maize a variety of by-products arise, the chief of which are maize gluten feed, maize gluten meal and maize germ cake. *Maize gluten feed* differs from *maize gluten meal* in that it contains the husk of the maize and hence is richer in fibre and poorer in protein; the two are, however, excellent foods and the gluten feed can be given to all classes of stock. *Maize germ cake* or meal is the residue left after removal of the oil from the germ and is mostly used for dairy cows.

Rice. In the East, rice is the foremost cereal and is fed along with pulses to livestock; it is deficient in protein, fat and minerals. When available here, it is fed to poultry.

For human consumption it is necessary to remove the hard husk from the grain, and this process, known as polishing, results in a product containing husk and portions of the kernel and germ and known as *rice meal*. This rice meal is quite a useful food provided that it does not contain more than 12 per cent fibre, but it is important to distinguish it from inferior rice grains ground up and given the same name. The latter is almost pure carbohydrate.

Other cereals which normally reach this country are *millet* and *sorghum*, both of which are used for poultry : *buckwheat* is usually classed under the same heading, although not a cereal.

Leguminous Seeds. Seeds of leguminous plants are richer in protein than the cereal grains and correspondingly lower in carbohydrate. They are often referred to as pulse grains.

Beans. These seeds, usually home grown, can be fed to all livestock but it is not advisable to feed when new. More often beans are ground to give bean meal, a product which, unfortunately, is very easily adulterated and does not keep well. Bean meal is given to dairy cows, though in excess it will produce a hard white butter ; to fattening cattle, especially to finish them off ; to pigs, in which it gives firm carcasses ; and to horses. This feeding-stuff can also be used in milk substitutes for calves.

Peas. Peas are not as popular as beans, and pea meal is less extensively used. In comparison, the meal is somewhat lower in protein but it can be used for similar purposes.

Other leguminous seeds are : *vetch* and *lupins*, each of which needs to be soaked and steamed to remove the bitter principle before feeding, although " sweet " lupins with a low alkaloid content are now available ; *lentils*, used for dairy cows and poultry ; and *chick peas*, which can be fed to most classes of stock. It should also be mentioned that imported leguminous seeds may contain poisonous seeds of considerable danger to stock.

Oil Seeds. Only two oil seeds need be considered here, linseed and sunflower seed, both of which have been used, as seeds, only to a very small extent in this country for feeding purposes.

Linseed. Linseed is rich in oil and protein, and the whole seed may be fed either after crushing or after scalding or cooking. It is specially useful for rearing calves, and also for sick animals. Linseed absorbs water and forms a jelly if soaked in warm water, but may become dangerous if allowed to remain in a moist condition because of the formation of small quantities of poisonous prussic acid from a cyanogenetic glucoside present in the seed in small quantities.

Sunflower. Sunflower seeds contain from 32 to 45 per cent of edible oil which is of great value for margarine, cooking and medicinal purposes. Consequently the seed, as grown, is too valuable to use as a stock food, but the seed residues, after the oil has been extracted and the husk removed, form a useful feeding-cake. Sunflower seed may be fed to poultry at the rate of from 1 to 2 oz. per day, and is said to be specially valuable during the moult.

Oil Cakes and Meals. Numerous seeds, chiefly grown in tropical and sub-tropical countries, are rich in oil : the oil is of considerable value in the manufacture of cooking fats, soap and other products, and the residues have proved to be excellent protein-rich feeding-stuffs for farm stock. The oil is removed by pressure or by solvent extraction. Formerly hydraulic pressure was used but this is now obsolete as it left too much oil (8–10 per cent) in the residue and was expensive in labour. Modern methods use either expeller or extraction procedures. In the first process the oil seeds are forced by a worm screw along a tube of gradually diminishing bore, thus squeezing out the oil and leaving a residue containing usually less than 5 per cent oil. In the extraction process the coarsely crushed oil seeds are subject to the action of an organic solvent such as hexane which dissolves out most of the oil, leaving a residue with usually less than 1 per cent oil. The volatile solvent is recovered and used again, and the residue is referred to as an extracted meal.

Some oil seeds have a fibrous seed coat which is removed by the process called decortication : the residue from decorticated seed will have a much lower fibre content than the residue from undecorticated seed, and the other constituents will vary accordingly. It is important to realise that oil seed cakes and cake meals are different forms of the same thing ; that extracted oil seed meals are clearly named : and that oil seed meals, e.g. linseed meal, are meals from which the oil has not been removed.

The chemical composition of all the important oil cakes is given in published Tables, and the figures should be consulted in conjunction with the following notes upon the individual materials.

Ground Nut Cake. This cake and the corresponding meal are available both in the undecorticated and the decorticated forms : the latter is particularly rich in protein. It is made from the earth nut or ground nut, which is the underground fruit of a tropical or subtropical leguminous plant. Both forms are used for feeding to dairy cows, fattening cattle, sheep, pigs and poultry, although the extracted decorticated ground nut cake is more useful in pig rations since it does not contain sufficient oil to affect the carcase quality.

Cottonseed Cake. This also is available in the decorticated and the undecorticated form and, in addition, the source of origin somewhat modifies the composition of the cakes. The undecorticated cake is very useful for cattle out at grass because of its " binding " action. Both cakes can be fed to cattle and sheep, but should be fed sparingly to pigs and young stock because of their high fibre content. Cottonseed products are poor in calcium, the protein quality is low, and cottonseed poisoning has caused trouble, particularly in America.

Palm Kernel Cake. This is made from the kernel residues of the African oil palm fruit, and it is somewhat gritty and absorbs water only slowly. In consequence cattle do not readily consume this cake, but if it is gradually introduced into the ration, possibly along with molasses, they will soon eat it. It is not as rich in protein as the other cakes and therefore can be used in larger quantities. Palm kernel cake is balanced for milk production and is usually recommended for the " steaming up " of dairy cows. It is also given to fattening cattle and small quantities may be fed to pigs.

Coconut Cake. This cake is sometimes soaked before feeding, and it is a very safe food for dairy cows, fattening cattle and pigs. It has the merit of producing a harder fat than do most of the oil seed products and hence can be used to offset the effects of these.

Linseed Cake. For many years this cake has had the reputation of putting a " bloom " on fattening cattle, an effect which may be due in part to its mild laxative action which, in turn, is dependent upon the mucilage which it contains. Because of this reputation linseed cake always fetches a high price, and, to economise in feeding, it is possible for the farmer to feed linseed cake in the later stages of fattening only, using cheaper cakes earlier on. Linseed cake or the cake meal will produce a soft oily fat if fed in excess and the biological value of the protein has been shown to be low for milk production ; nevertheless, it is an excellent feeding-stuff. Linseed cake meal is quite distinct from linseed meal, which consists of the ground whole seed ; this latter material still contains all the oil and is used in small quantities for sick animals. Whole unground linseed should never be fed unless it has been boiled or well soaked in water. As already mentioned linseed products may sometimes cause poisoning in young stock if due care is not taken in feeding them.

Soya Bean Cake is rich in protein and contains an oil which is somewhat laxative. Extracted soya bean meal on the other hand has a low oil content. Dairy cows, fattening cattle, pigs and poultry can all be fed on it. It is laxative but quite safe in normal amounts, and is used to balance the cereals in a ration.

Miscellaneous Oil Cakes. Amongst the lesser-known cakes and meals are *Rape*, *Sunflower*, *Safflower* and *Sesame*. The former is not always safe because it may cause irritation of the alimentary tract, but the others are satisfactory when used in the right way.

Animal Products. These are mainly by-products from slaughterhouses and the fishing industry.

Meat Meal and Meat-and-Bone Meal. These products are made from trimmed-off portions of animal carcases shortly after slaughter : they are subjected to cooking in steam-jacketed cauldrons until the moisture content is reduced to less than about 10 per cent. Surplus fat is drained off and the residue is then pressed in an expeller to remove the greater part of the fat. The quality of the material is dependent upon the proportion of bone included, the higher the proportion of bone the lower will be the protein content. Meat meals must contain by law at least 55 per cent protein ; meat-and-bone meals between 40 and 55 per cent protein ; neither type of product may contain more than 4 per cent salt. These legal definitions limit the amounts of fat and bone in these products which can be usefully employed in the rations of pigs and poultry.

Whale Meat Meal. This is a product of a very high protein content and consists very largely of the flesh of the whale with a minimum amount of included bone. The processing is similar to that of meat meal.

Blood Meal. The coagulate from slaughterhouse blood is pressed to remove as much serum as possible and it is then dried under vacuum in steam heated cylinders to a moisture content of under 10 per cent. The product contains some 80 per cent protein, but it is normally a low source of minerals. It may be used up to a level of 5 per cent in the rations of pigs.

White Fish Meal. This consists of the dried and ground flesh and bones of white (i.e. non-oily) fish, the drying being effected at low temperatures to avoid damage to the nutritive value of the proteins. By the Fertilisers and Feeding Stuffs Act the product must derive from white fish and must not exceed contents of 6 per cent oil and 4 per cent salt. These legal requirements ensure a very high standard type of article that is particularly valuable for pigs and poultry. It normally contains at least 60 per cent protein ; its judicious use involves virtually no risk of tainting carcases or eggs.

Other Fish Meals (*Herring, etc.*). These are products of oily fish such as herring, pilchards and so on. After being partially cooked they are subjected to hydraulic pressure to remove as much oil as possible, and then the residue is processed similarly to that of white fish meal. These meals usually contain 7 to 10 per cent oil and are often richer in protein than white fish meal, and correspondingly lower in bone content, as reflected in their figures for calcium and phosphorus. The presence of this oil involves a slight risk of tainting edible products from the animals to which these types of fish meal are fed, but withdrawal of the fish meal some three weeks before slaughter will ensure that no taints are present in the carcase meat of pigs.

THE DIGESTIBILITY OF FEEDING STUFFS

The crude or analytical composition of a feeding stuff gives a very limited indication of its nutritive value to animals, since the latter can only utilise those portions of the food that are capable of being digested. Consequently in order to determine the digestibility of a food we have to use the living animal.

Digestion trials can be carried out with any class of animal, but the results obtained can be applied strictly only to that class. Again, the choice of animal depends upon a number of physical considerations such as available space, the quantities of food given, the weight of excreta obtained, and associated problems of sampling accurately the food and the excreta. Anatomical considerations may involve modifications of the technique employed ; in poultry, for example, the droppings represent a combined faecal and urinary excretion, and digestibility trials in consequence are more difficult to carry out.

Digestibility Trials. Most digestibility work on ruminants is conducted with sheep. Although the results so obtained are not identical with those obtained for the same food using cattle, the differences are not so great as to prevent those results from being applied to cattle. On the other hand, it would be incorrect to apply information derived from the use of sheep to pigs or to poultry. The castrated male sheep (wether) is usually employed for work on ruminants, because of the convenience of its size, the quantity of food consumed daily under laboratory conditions, and the firmness and ease of sampling of the faeces.

The assumptions made in carrying out a digestibility trial include that :

(1) the difference between what is eaten and what is excreted in the faeces is that which is digested ;

(2) the degree of digestibility of a food is independent of the animal's inability to take exercise whilst the trial is in progress.

(3) the degree of digestibility is independent of the plane of feeding.

(4) the degree of digestibility is independent of the breed, strain and individuality of the experimental animals.

The main sources of error probably lie in the first assumption.

The *faeces* of an animal comprise (*a*) undigested food residues, possibly altered in form by bacterial action in the large intestine, (*b*) the metabolic debris, resulting from the sloughing off of epithelial tissue from the walls of the alimentary tract during the passage of the food, (*c*) the unabsorbed residues from digestive fluids and juices added to the food in order to carry out the various phases of digestion and (*d*) certain mineral matter which is brought into solution and absorbed from the small intestine and re-excreted from the blood stream into the faeces via the large intestine. Of these, (*b*) and (*c*) are inherent in the act of digestion so that really we determine the degree of apparent digestibility of the food. Factor (*d*) may appear at first sight to be an insuperable difficulty, but since the digestibility of the mineral matter is not involved in any assessment of the energy content of the food, trials are carried out in the knowledge that whereas the returned mineral matter affects the weight and composition of the faeces, these are self-compensating and do not affect the total weight of organic matter voided.

The essential point to grasp is that a digestion trial is based on quantitative data of weights of individual food fractions given and voided. We supply the animal with daily known weights of food of composition determined by analysis ; we measure the daily weights of faeces voided and analyse this excreta just as we analyse a food. The feeding of 1000 g. hay containing 10 per cent crude protein involves supplying the animal with 100 g. of protein in the hay ; an average excretion of 2000 g. wet faeces containing 2 per cent crude protein means that in the faeces were 40 g. protein. So we argue, 60 g. protein from the hay have been digested from the 100 g. supplied, a *percentage digestibility* of 60 per cent ; or, putting it another way, the *digestion coefficient* is 60 per cent. The original hay contained 10 per cent protein of which 60 per cent is digestible and 60 per cent of 10 is 6. Hence this hay contains 6 per cent digestible protein.

Similar calculations and reasoning can be applied to the organic matter, the ether extract, the nitrogen-free extractive and the crude fibre of the hay. Indeed, it can be applied to the mineral matter as well, but we know in advance that we shall obtain a falsely low result since part of the mineral matter has been digested but has been re-excreted into the faeces.

No consideration is given to the urine in this reasoning ; this is because what is excreted in the urine represents, amongst other things, the end-products of the metabolism by the body of the digested food. A digestion trial is primarily concerned with the fate of food in its passage through the alimentary canal. It is usual to collect, measure and analyse the urine at the same time since a great deal of additional information on the balance of certain elements in the body can be obtained for relatively little extra analytical work ; but essentially the urine plays no part in digestibility trials.

It is not necessary to go into full details of the technique involved, except to mention that although a constant weight of food may be fed daily there are considerable irregularities in the daily weights of faeces excreted. Consequently, trials of less than one week in duration can give very misleading results, and it is usual to work for periods of 10 days once the animal has become accustomed to the restraint of the metabolism stall and the necessary harness to ensure complete collection of faeces and the avoidance of contamination with the urine.

A modification of the technique is required where the digestibility of concentrated foods is being studied. It is essential for a ruminant animal to ruminate in order to be normal, and rumination is adversely affected by an all-concentrate diet. The modified technique involves an initial period of feeding with a roughage such as hay during which its digestibility is determined. This is followed by a reduction in the amount of hay fed and the introduction of the concentrate food. The combined digestibility of both foods is then determined, whence by calculation the digestion coefficients of the concentrate food can be derived. Such a technique is very time-consuming, often involving the animal in a month's sojourn in the metabolism crate, but it appears to be the only reliable method of obtaining the necessary data.

FACTORS INFLUENCING DIGESTIBILITY

It has already been stated that results of the determination of the digestibility of a feeding stuff by one species of animal do not necessarily apply to another species. The differences in results are related to the ability of the animal to deal with the fibrous portion of the food. Ruminants have the greatest capacity for digesting fibre, although horses and rabbits, in both of which there is a relatively large caecum, can also cope reasonably efficiently with fibre. The major difference is that in the ruminant the complex biological changes that occur in the rumen takes place *before* normal gastric and intestinal digestion, whereas in other species the main digestion of fibre occurs *after* normal alimentary digestion. This peculiar attribute of the ruminant may allow of better subsequent digestion of non-fibrous constituents, because the cellulose cell-walls of the plant have been ruptured, making possible a better attack by the normal gastric and intestinal digestive juices on the contents of the cells of the food material. Hence fibrous foods are generally better digested by ruminants than by other classes of animals.

The physical size of the food particles is also of importance. Whole grains, unless thoroughly chewed may, in part, tend to pass through the alimentary tract unchanged and appear intact in the dung ; the same grains, even coarsely ground, will be better digested. On the other hand, with ruminants fine grinding to a meal of coarse fodders may lead to less efficient digestion, because in fine meal form the fodder may pass through the rumen and reticulum too quickly, allowing too little time for the microbial population there to do its work of splitting the fibre.

The level of feeding may exert some influence on digestibility, and there is evidence that animals fed to appetite with a particular food digest this less efficiently than at a lower plane of feeding. Certain foods, e.g. raw potatoes, are less efficiently digested by pigs and poultry than when fed cooked, although there seems little justification for steaming or cooking foods for most forms of livestock.

Foods that are naturally laxative and pass rapidly through the alimentary canal are less efficiently digested than when their rate of passage is slowed down. Spring grass fed in conjunction with some long fibrous food such as hay, straw or undecorticated cotton cake, is more efficiently digested than when fed alone. There is little scientific evidence to support the use of condiments as an aid to digestion ; the fact that better results are sometimes obtained with spiced foods is probably more likely due to increased food consumption than to a higher level of digestibility of the food itself.

Digestibility Coefficients only a Guide. Finally, although one has to accept tacitly published figures for digestibility coefficients of the various components of the food, it has to be remembered that these have usually been obtained with a very limited number of animals. In the absence of more detailed information these probably represent the best figures available, but they are really no more than a guide and should certainly not be accepted as absolute in any sense. For practical purposes they have to be used, but the reader should always be aware of the many assumptions that have to be made in this class of work and should accept the figures as indicative rather than absolute.

THE UTILISATION OF FOOD

In the course of digestion the soluble products of the food pass through the walls of the intestine into the circulating blood stream and thence to all parts of the body (see p. 507). In the various cells of the body, these products undergo a large number of very complex biochemical reactions. The net effect of these reactions is that the digested products of the food are either broken down ultimately to very simple substances, subsequently excreted from the body in the breath or the urine, with the liberation of energy, especially heat ; or they are built up into substances that form part of the body such as muscle and body fat, and secreted products such as eggs and milk. We refer to the breaking down reactions as *catabolism*, and the building-up processes as *anabolism*. The over-all term *metabolism* covers both types of process.

For agricultural purposes food has two main functions. It provides for the *maintenance* of the animal, covering as it were the requirements for existence and normal health, and for the *production*, the normal economic reason for keeping the animal. Production may assume the form of growth and development, fattening, milk production, egg production, work, growth of wool or fur, and reproduction. Maintenance is, normally, a first charge on the food, and production begins only after maintenance needs have been met. In some circumstances the animal may draw on its bodily reserves in an effort to sustain production, even if the diet is insufficient, but obviously this cannot go on indefinitely.

MAINTENANCE

Maintenance is normally considered to be the state of the non-producing animal, in normal health and keeping its liveweight constant. Domestic animals are warm-blooded, with a constant temperature usually well above that of the environment in which they are placed. Consequently they are regularly losing heat to that environment. They breathe and move about, their hearts are pumping blood around the body, and even when physically at rest there is a great deal of activity going on within the body. Moreover, there is a certain amount of wear-and-tear that affects every cell and every part of the body. Thus the food has the job of providing the energy for the vital processes of the body, and materials to make good this normal wear-and-tear. Normally the energy needed is provided from digested carbohydrates, fibre, fats and oils, while the digested proteins cover most of the replacement needs. When the vital needs of the animal are met by the food without any gain or loss of weight, then the animal can be said to be receiving a maintenance ration.

This definition involves the assumption that liveweight changes necessarily reflect changes in the energy, protein and also the mineral status of the body. Over a reasonably long period of time this is broadly true, but over short periods liveweight changes can prove very unreliable. The major constituent of the animal body is water, and even a 1 per cent change in the water status of a 1000 lb. bullock amounts to 10 lb.

But the most important factor causing variations in liveweight of an animal from day to day is that of " fill ", that is the weight of the contents of the digestive tract. A 1000 lb. bullock at grazing may well consume 1½ cwt. fresh grass each day, and may drink another ½ cwt. of water. Variations in the weight of dung and of urine voided each day can be very considerable, so that constancy of liveweight by itself can, over short periods of time, be a most unreliable index of the adequacy of a maintenance ration.

The daily output of heat from an animal can also vary. It depends to some extent on the environmental temperature, although the animal has some control of the degree to which it loses heat to its surroundings. The amount of energy involved in exercise is also variable, although this can be reduced by keeping the animal under stall conditions. Even so there is a greater output of heat when the animal is standing compared with lying down.

The concept of an adequate maintenance ration based on a steady liveweight figure can hardly be regarded as scientific except over a reasonably long period of time ; for fundamental investigational work, as we shall see later, a somewhat different definition has had to be made. Nevertheless, for general agricultural purposes a maintenance ration can be looked upon as supplying the nutrients necessary to maintain an animal in health without appreciable change in its liveweight.

PRODUCTION

The economic purpose of keeping farm animals lies in the very varied forms of production. Production may consist of straightforward growth, development and fattening ; it may involve materials removable from the body such as milk, wool, eggs ; it may be manifest in draught power or work, or it can involve the processes of reproduction, both with male and female animals. Different types of nutrients are involved in the various forms of production, and ultimately these derive from the digested portions of the food. Requirements of nutrients, both absolute and relative to the different species and types of production, are variable, and it is the aim of nutritional science to attempt to express in measurable form the nutrients necessary for various purposes.

There is considerable variation in productive requirements, not only between species and in relation to different forms of production but also within species and between individuals. The nutritionist attempts to define within determinable limits what are the specific requirements for various forms of production for what might be termed the average animal under average conditions. Indeed, some of the present-day doubts about figures for production requirements of the past are merely giving recognition to the reality of biological variation. Because of this variation nutrition must be looked upon both as an art and a science, and *scientific feeding should be regarded more as an intelligent guide than a dogmatic assertion of the exact needs of the animal.*

Nevertheless, the student of animal nutrition has to be aware of the commonly accepted feeding standards provided by modern science. The standards are expressed in many different ways, and may involve a large number of different factors. The major needs of any animal for both maintenance and production relate to an adequate supply of energy in the food and the provision of adequate levels of digestible protein of appropriate biological value ; minor needs are for adequate levels of appropriate vitamins and minerals in relation to the type of production called for. Practically all these needs are met by the food, although some minor factors may derive from the circumstances of an out-door life. It is now necessary to consider some of the more essential characteristics of feeding stuffs needed to provide for the energy requirements of animals for both maintenance and production, and with these the provision of adequate protein as well.

ENERGY CONCEPTS OF FOOD

The principal sources of energy derivable from food are carbohydrates, fats and oils ; no other component can take the place of proteins in relation to their specific functions, but supplies of protein, surplus to the animal's immediate needs, can serve as sources of energy after the nitrogenous portions of the surplus proteins have been split off, metabolised, and excreted into the urine. For the present, therefore, we shall consider protein to be also a source of energy, although strictly speaking this concept applies only to proteins surplus to the animal's needs.

The living animal is able by the various processes of digestion and metabolism to transform the energy of food into other forms of energy. In nutritional science energy is measured after it has been transformed into liberated heat, which in turn is measured by the physical process of calorimetry and expressed in terms of heat units. The standard unit of heat is the kilo-calorie (K-cal) which is the amount of heat required to raise the temperature of 1 Kg. water through 1° C. (from 15° C. to 16° C.).

GROSS ENERGY VALUES

When a food is burnt in an atmosphere of oxygen in a bomb-calorimeter the heat liberated can be measured in terms of K-cals per gram of food, and this is referred to as the *Gross Energy Value* of the food. The animal is not as efficient in its combustion of the food as the bomb, and part of the total energy of the food is lost from the body in the form of undigested solid matter (the faeces), the incompletely oxidised nitrogenous parts of the digested food appearing in the urine, and in the production of combustible gases produced by bacterial action on the food in its passage through the alimentary tract. This latter fraction is quite appreciable with ruminant animals which produce and belch out considerable amounts of the combustible gas methane. These losses, therefore, reduce the potential of the Gross Energy Value of the food by the combustible value of the excretion products, and the residual part of the original energy is termed the *Metabolisable Energy* or *Physiological Heat Value* of the food.

Even this reduced Metabolisable Energy Value of the food is not all available to the animal as was shown by the classical work of Armsby and his co-workers in the U.S.A., for on placing a steer in an apparatus (the animal calorimeter) and feeding it on different planes of nutrition with the same food he was able conclusively to demonstrate a greater evolution of heat with increasing levels of feeding. This wasteful and uneconomic transformation of some of the energy of the Metabolisable Energy fraction of the food into heat which was dissipated from the animal body was termed Thermic Energy (or, when related to each 100 lb. of the food, the Increment of Heat Production) so that only what was left was actually available to the animal for its physiological needs.

This available energy is called the *Net Energy Value* of the food. Hence Net Energy Value of 100 lb. food = Gross Energy Value of 100 lb. *less* the energy lost in the faecal, urinary and gaseous excreta derived from 100 lb. of food, *less* the Thermic Energy per 100 lb. (or the Increment of Heat Production).

For large-scale work the Kilo-calorie is too small a working unit of heat and the Therm,[1] equal to 1000 K-cals, is employed.

A comparison of results obtained from a low-energy, poorly digested food such as wheat straw, with a high-energy, well-digested food like maize meal, gave the following results.

Therms per 100 lb.-Dry Matter in Food

	Gross Energy.	Energy losses in Excreta.	Metabolisable Energy.	Heat Increment.	Net Energy.
Wheat Straw . .	201·6	138·9	62·7	51·6	11·1
Maize Meal. . .	201·5	50·6	150·9	58·3	92·6

The heat of combustion (Gross Energy Value) of the straw and the maize were almost identical. The lower degree of digestibility of the straw is reflected in the much greater loss of energy in the excreta (especially the faeces) with the result that the Metabolisable Energy value of the maize was nearly 2½ times that of the straw. The output of heat, reflecting the work of digestion and the plethora of nutrients in the tissues of the body, is larger for the maize than the straw, but with the latter it is such a high proportion of the Metabolisable Energy that only about 5 per cent of the original energy of the food is available for productive purposes compared with about 47 per cent of that in the maize meal.

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[1] The "Therm" used here must not be confused with the "Therm" used as a unit of gas supply.

Useful figures to remember are those for starch which has a Gross Energy Value of 186·1 Therms per 100 lb., a Metabolisable Energy value of 170·7, and a Net Energy Value of 107·1 (i.e. about 58 per cent of the Gross Energy), as applied to ruminant animals.

The concept of Net Energy Values is perhaps the most fundamental one in assessing the nutritive value of fodders, but it is more complicated and difficult to follow than the essentially similar but more practical concept due to Kellner—the Starch Equivalent System.

STARCH EQUIVALENT VALUES

Kellner argued that if an adult animal were on a true maintenance ration and additional food were then given, the extra energy from this food would be stored in the animal body in the form of fat, since the carbohydrate content of the body amounts to only about 1 per cent of the weight of the body. Any slight storage of protein could be converted into its energy equivalent of fat, on the basis that 5 g. stored body protein are equivalent, in *terms of energy*, to 3 g. body fat.

Kellner placed a bullock in a closed chamber—the respiration chamber—so that he could feed it, collect the faeces and urine, and determine the gaseous output of carbon dioxide and of methane and other combustible gases arising from bacterial action in the rumen. He adjusted the food intake so that the animal was approximately in carbon and nitrogen equilibrium. This meant that the intake of carbon in the food exactly balanced the output of carbon in the faeces, urine, the " brushings " from the coat of the bullock and the gaseous excreta, and that the intake of nitrogen was equal to that put out in the faeces, urine and the coat " brushings ". This provided the animal with a true maintenance ration.

Next, in addition to this maintenance ration, he gave known weights of pure nutrients such as starch, sugars, proteins, cellulose, and fats and oils, which were all converted into fat in the body of the bullock, and again measured the intake and output of carbon and nitrogen in the solid, liquid and gaseous excreta. From a knowledge of the carbon and nitrogen content of body protein and of the carbon content of body fat, he was able to calculate the storage of carbon (and any slight storage of nitrogen) in the body and hence the actual weight of fat stored for each unit of weight of the pure nutrients fed. For example, Kellner found that 1 kg. starch led to the storage of almost 0·25 kg. fat in the body in the conditions described, and 1 kg. protein to the storage of 0·235 kg. fat. By dividing the various weights of fat stored per kg. nutrient by the figure obtained for starch (actually

0·248 kg.), he was able to calculate the relative fat-forming capacities of different pure foods. These are shown below :

Relative Fat-forming Values of Different Foods

1. Pure Starch	1·00
2. Fibre (Cellulose)	1·00
3. Sugars	0·76
4. Protein	0·94
5. Fats (*a*) from oil seeds	2·41
(*b*) from cereals and legumes	2·12
(*c*) from roots, and green and coarse fodders	1·91

Work with bullocks on a carefully adjusted maintenance ration in a respiration chamber is very time consuming, exacting and laborious. Kellner argued that if the various digested components of a mixed feed behaved, from the point of view of their fat-forming values, like pure nutrients, he should obtain the same results as with the use of the respiration chamber. To test this, he again put his bullock on a true maintenance ration, and fed various concentrated foods like decorticated oil seed cakes, cereals and so on. To his delight he found that the fat-forming capacities of these foods, relative to starch, were very closely similar to those calculated from the digested components employing the factors outlined above ; within the limits of experimental error they were generally slightly less.

The " ideal " or " theoretical " Starch Equivalent value of a food was calculated by adding together the digestible nitrogen-free extractives, the digestible crude fibre, the digestible protein × 0·94 and the digestible oil × 2·41, or 2·12 or 1·91, according to its origin, as shown above. The " actual " starch equivalent value was obtained from the actual weight of fat stored divided by 0·248 (the fat-forming value per unit weight of starch). The ratio between the two values was expressed as a Value Number (or " V ") thus

$$V = \frac{\text{actual weight of fat produced per unit weight of food}}{\text{weight of fat per unit of food predictable from digestible composition}}$$

" V " numbers for concentrated foods usually lay between 0·95 and 0·98.

When Kellner employed less concentrated, mainly more fibrous, foods, the discrepancy measured by " V " was larger, i.e. the " V " values became smaller. For example, " V " for bran was shown to be 0·77, for swedes 0·85, for good meadow hay only 0·67 ; Kellner quickly saw that the more fibrous the food the smaller was the " V " value, and that each 1 per cent crude fibre in the food lowered the predicted Starch Equivalent (S.E.) value of the food by 0·58 unit.

For coarse fodders he arrived at the relationship

Actual S.E. value = Theoretical S.E. minus 0·58 × % crude fibre.

For green fodders the figure for the fibre correction factor varied from 0·29 to 0·58, perhaps a rather unsatisfactory and arbitrary method of applying a correction factor.

It is now possible to define the Starch Equivalent value of a food as *the number of lb. of pure starch, which when fed in addition to a true maintenance ration, will lay on in the adult ruminant animal the same weight of fat as* 100 *lb. of the given food.*

Each 1 lb. of starch or starch equivalent fed in addition to a maintenance ration to a ruminant causes the storage of 0·248 lb. fat or 1071 K-cals Net Energy, in the body.

Unfortunately there are still many difficulties in assessing the starch equivalent values of roughages and other fibrous foods. After Armsby had developed the use of his animal calorimeter, he found that whereas his values for energy stored from concentrated foods agreed reasonably well with those of Kellner, his values for coarse fodders were usually appreciably higher. The practice in this country now is to increase arbitrarily the Kellner S.E. values for coarse fodders by 20 per cent, following a suggestion by the late Professor T. B. Wood at Cambridge. An example will make this clear in respect of meadow hay.

STARCH EQUIVALENT OF MEADOW HAY

Crude Composition	*(per cent)*	*Digestible Composition (per cent)*	*Factor*	*"Theoretical" S.E.*
Moisture	15·0	—	×	
Crude Protein	9·0	4·6	(0·94)	4·32
Ether Extract	1·9	1·0	(1·91)	1·91
Crude Fibre	26·7	12·8	(1·00)	12·8
Nitrogen-free Extractives . .	42·0	24·0	(1·00)	24·0
Total Ash	5·4	—		43·03

Fibre Correction = 0·58 × 26·7 = 15·50
Kellner S.E. (Unadjusted) = 43·03 − 15·50 = 27·53
Adjusted S.E. (Wood's 20 per cent increase) = 27·53 × 1·2 = 33

The starch equivalent system is essentially a measure, under specified conditions, of the fat-forming capacity of a food ; it will be noted in the calculations involved that protein serves essentially as a source of energy since the protein requirements of the adult animal have been met by the true maintenance ration. Whereas 1 lb. S.E. for fat forming purposes involves the storage of 1071 K-cals, for milk production purposes (due to the secretion of protein into the milk) 1 lb. S.E. corresponds to the storage of about 1360 K-cals for milk production.

Notwithstanding the limitations and assumptions involved in the S.E. system of food evaluation, it does form a useful guide to the scientific rationing of ruminants. The factors were worked out with ruminant animals, and hence it is wrong to use the term S.E. for evaluation of foods for pigs and poultry.

FOOD OR FODDER UNITS

Fundamentally, the starch equivalent system is another method of expressing net energy values of foods. In Northern Europe a further modification has been involved in what is termed the Food (or Fodder) Unit system. It is empirical and, whilst based on Kellner's results, has been modified to take into account the results of practical group-feeding trials. The food unit is 1 kg. of average barley and corresponds to $\frac{2 \cdot 2 \times 71}{100}$ or 1·56 lb. S.E. (In this calculation 1 kg.= 2·2 lb. and the S.E. of barley = 71 per cent.)

A further modification of the system has been evolved for pigs and poultry, and is known as Total Digestible Nutrients (T.D.N.). This is an expression summing the digestible nitrogen-free extractives, the digestible crude fibre, the digestible protein, and 2·3 times the digestible ether extract. Broadly, it corresponds to the uncorrected " theoretical " starch equivalent values of Kellner, and for concentrated foods the T.D.N. values are numerically very close to those for S.E. For less concentrated foods, and in particular the more fibrous foods, the T.D.N. system of evaluation gives excessively high values. If we take the figures cited on page 568 for the digestible composition of the specified sample of meadow hay, the T.D.N. value works out at 43·7, much higher than the uncorrected Kellner S.E. value of 27·5 or the Wood-corrected value of 33. Whatever may be the inaccuracies of the various Kellner correction factors, they at least help to avoid the patent over-evaluation of the more fibrous foods inherent in the T.D.N. system.

MAINTENANCE STANDARDS

Kellner worked with cattle in store condition to try and assess the amounts of coarse fodders required to maintain them in carbon and nitrogen equilibrium, and found that the 9 cwt. animal (1000 lb.) required 6·0 lb. S.E., *including* 0·7 lb. digestible protein, to achieve this. It seems logical to assume that larger animals would have higher requirements and smaller ones lower requirements than these. The maintenance need of food by an animal should balance the amount of heat evolved in a 24-hour day, and this loss of heat is more closely related to the surface area of the animal than to its body weight. In general, surface area is not directly proportional to liveweight but to a power of that weight. Rubner's Surface Law implied that the rate of metabolism was a function of the surface area and that $\frac{\text{Total Heat evolution (K-cals)}}{\text{Surface Area}}$ was approximately constant.

Surface area was formerly assumed to be proportional to the two-thirds power of the weight, though more recent biometric work has suggested the power of 0·73 : in other words maintenance requirements vary as $(\text{Live Weight})^{0 \cdot 73}$. If we follow the " two-thirds " power law, M is proportional to $W^{\frac{2}{3}}$ or $M = kW^{\frac{2}{3}}$. The value for M at 9 cwt. liveweight is 6·0 lb. S.E. $\therefore k = 6/9^{\frac{2}{3}}$

The maintenance requirement of a 12 cwt. animal (assuming the validity of the law) is therefore

$$\frac{6 \times 12^{\frac{2}{3}}}{9^{\frac{2}{3}}} = 6 \times (1 \cdot 333)^{\frac{2}{3}} \text{ or } 7 \cdot 3 \text{ lb. S.E.}$$

Similarly, calculations can be made for other liveweights.

At all adult liveweights the digestible protein requirement is between 0·6 and 0·8 lb. The maintenance requirements of young animals cannot be truly calculated from the formula since experience suggests that they are appreciably higher than predicted. It is difficult to define under practical conditions exactly what is meant by maintenance, since apart from obvious heat losses from the surface some allowance has to be made for a normal amount of movement, of standing up and lying down.

For practical purposes the maintenance requirements of the stall-fed or yarded animal over the liveweight range 7 to 12 cwt. can be considered to vary directly with the liveweight, and to change by about 0·5 lb. S.E. daily per cwt. liveweight up or down from 9 cwt. within this range. This puts the normal maintenance requirement for the 7 cwt. animal at 5 lb. S.E., for the 10 cwt. animal at 6·5 lb. S.E., and for the 12 cwt. animal at 7·5 lb. S.E.

Again, for practical purposes, there is little to be lost by the very empirical assumption that the daily digestible protein requirement is one-tenth of the S.E. in lb. plus 0·05 lb. This puts the maintenance digestible protein requirement of the 7 cwt. animal at 0·55 lb., the 10 cwt. animal at 0·70 lb. and the 12 cwt. animal at 0·80 lb. The figures are perhaps slightly on the generous side, but there are bound to be individual variations, and since maintenance in practical terms is virtually impossible to define there is probably no serious fault in being a little generous.

PRODUCTION STANDARDS

In the adult ruminant the principal forms of production are liveweight increase, largely in the nature of laying on of fat, and milk production. It is with the latter that the classical conception of production has been subject to most criticism of recent times, owing to the very wide range of production levels attainable from the modern dairy cow. The farmer is faced with extremes of production—from under a gallon of milk to something of the order of 10 gallons or more. The classical conception of production was that if x units of nutrients were required for one unit of production (say a gallon of milk or 1 lb. liveweight gain) an expectancy of n units of production would require nx units of nutrients. If m units of nutrients were required for maintenance the total nutrient requirement of the animal would be $m + nx$ units.

Such a formula necessarily assumes that food requirements for production are the same at all levels of production : that if 4 lb. concentrates are required for one gallon of milk, 36 lb. would be required for nine gallons. Various authorities have pointed out the law of diminishing returns, to the effect that with increasing levels of nutrient intake the response tends to diminish.

Most controversy has centred around the modern dairy cow with her in-bred capacity to produce high levels of milk. In her efforts to respond to this genetic capacity she may well, and usually does, draw upon her bodily reserves in order to sustain high levels of production. As against this, the energy value of a gallon of milk at high levels of production may well be lower than normal, reflected usually in a lower-than-average butterfat level. There seems little doubt that the relationship between nutrient intake and milk output is *not* a straight line as the equation $m + nx$ would necessarily imply, but is curvilinear. On the other hand experience suggests that at lower levels of milk production, say, under 5 gallons, the deviation of the curve from a straight line is for practical purposes negligible, and that the ability of the cow to milk off her back tends to make up for the deficiency in nutrient intake between requirement and a constant rate of food intake based on so many lb. per gallon.

PRACTICAL APPLICATIONS

Feeding is unlikely ever to be a mathematically exact science, and for practical purposes it should be remembered that best results are obtained when the art of feeding is allied to the science. No two animals ever respond in identical manner, despite absolute identity of treatment, but the fact remains that most animals conform within reasonable limits of variation to standards that have been scientifically worked out.

In the discussions on requirements and standards that follow some dogmatic, unqualified assertions have necessarily to be employed. The practically-minded reader should accept these assertions on the understanding that they are guides to the art of feeding and may require slight modification in the light of the individuality of the animals and the circumstances in which they are being kept.

Appetite. One most important factor limiting an animal's productivity is its capacity to take in food. Simple experience will show that a bullock or cow can eat a greater weight of mangels than of hay ; it is not a question so much of palatability or acceptability of the food as the fact that an animal eats to satisfy its need for " fill ". The simplest conception of daily appetite capacity is bound up with the actual intake of food dry matter, and experimentally this normally (for cattle) is between about 2½ and 3½ lb. dry matter per live cwt. If for illustration we take the 10 cwt. cow or bullock, we can reasonably predict that its intake of dry matter daily will lie between 25 and 35 lb. Foods vary enormously in their dry matter levels, ranging from about 10 per cent for succulent foods like mangels to 85 per cent or more for dry foods like cereals, oil cakes and average hay. If we tried to supply 30 lb. dry matter in the form of mangels our 10 cwt. animal would theoretically have to consume about 300 lb. daily : 30 lb. dry matter would be contained in 35 lb. hay. Now if hay or mangels were the sole food of such an animal, it is highly unlikely that even with the food before it for 24 hours the animal would eat anything approaching these quantities. Balanced dairy cake is usually a very acceptable food, but there are probably few animals that would eat day after day the 33 lb. or so of such cake as would supply 30 lb. dry matter. But a daily ration of 14 lb. hay (= about 12 lb. dry matter), 60 lb. mangels (= 6 lb. dry matter) and 14 lb. dairy cake (= about 12½ lb. dry matter) could quite comfortably be eaten by a dairy cow giving 4 gallons of milk.

The imperfections of dry matter intake as an absolute measure of appetite are well recognised, but with a mixed and varied type of diet such an intake acts as a useful guide to daily food assessments.

FOOD REQUIREMENTS OF ADULT CATTLE

The following table sets out in condensed and simple form a useful practical guide to food and nutrient requirements of adult cattle.

TABLE 6

FOOD REQUIREMENTS OF ADULT CATTLE

Appetite

Allow 2½–3 lb. dry matter intake per live cwt. For dairy cows the upper limit of food intake may be of the order of 3½ lb. D.M. per cwt.

Maintenance

Requirements are as follows:

Live Wt. (cwt.).	Starch Equivalent (lb.).	Digestible Crude Protein (lb.).
7	5·0	0·55
8	5·5	0·60
9	6·0	0·65
10	6·5	0·70
11	7·0	0·75
12	7·5	0·80

Milk Production

Requirements per gallon

	Starch Equivalent (lb.).	Digestible Crude Protein (lb.).
(1) Non-Channel Island breeds . .	2·5	0·5
(2) Channel Island breeds (average butterfat levels of 4 per cent or more)	3·0	0·7

Fattening

Requirements per each lb. daily liveweight gain

	Starch Equivalent (lb.).
Early fattening (store) . .	2·25
(fresh) . .	2·5
Half fat	3·0
Fat	4·0

The daily protein requirement at all levels of fattening to include both maintenance and production is between 1¼ and 1½ lb. digestible crude protein. The higher standard is suggested where (as in modern practice) younger animals are growing and fattening simultaneously.

CONSTRUCTION OF A DAIRY RATION

Reference to the standards for ordinary (i.e. non-Channel Island) milk production shows a requirement per gallon of 2·5 lb. S.E. and 0·5 lb. digestible crude protein. This gives an S.E. : D.C.P. ratio of 2·5 : 0·5, or 5 : 1. The foods used in dairy production rations are usually the concentrated foods, cereals, oil seed cakes and so on. If the S.E. : D.C.P. ratios of the commoner of these foods are grouped according to whether these ratios are wider or narrower than about 5 : 1 we have three possibilities.

(1) "*Cereal*" *types* (Ratio wider than 5 : 1)

	S.E. (per cent).	D.C.P. (per cent).
Barley	71	6·5
Oats	60	7·5
Maize	77	7·7
Dried Sugar Beet Pulp .	60	5·0
Maize Germ Meal . .	84	10·0

(2) "*Balanced*" *types* (Ratio about 5 : 1)

	S.E. (per cent)	D.C.P. (per cent).
Wheat Bran . . .	45	10
Palm Kernel Cake . .	73	17
Coconut Cake meal . .	74	15
Maize gluten feed . .	76	19

(3) "*Protein*" *types* (Ratio much narrower than 5 : 1)

	S.E. (per cent).	D.C.P. (per cent).
Bean Meal . . .	66	20
Dec. Ground Nut Cake .	70	39
Soya Bean Meal . .	64	38
Linseed Cake . . .	74	25

Obviously, then, to construct a balanced dairy ration we need appropriate mixtures of Groups (1) and (3) to which we may add in reasonable proportions foods from Group 2. What must always be appreciated is that each type of food makes some contribution to both the S.E. and D.C.P. components.

We have also to consider the relative degree of "concentratedness" of our final mixture. A ration of which 4 lb. contribute some 2·5 lb. S.E. and 0·5 lb. D.C.P. must have an S.E. value of $\frac{2{\cdot}5}{4} \times 100$ or about 63 per cent and a D.C.P. value of $\frac{0{\cdot}5}{4} \times 100$ or 12·5 per cent. Similarly a 3½ lb./gallon mixture needs an S.E. of about 71·5 per cent and a D.C.P. of 14·3 per cent. ; a 4¼ lb./gallon mixture an S.E. of about 61 per cent and a D.C.P. of about 12 per cent. Evidently, if we are aiming for a 3½ lb.-to-the-gallon mixture, our usage of relatively low S.E. foods such as oats, beet pulp and soya must be limited unless we compensate with really high S.E. foods such as maize and its by-products.

Simple Binary Mixtures. Working out binary mixtures, or mixtures made up of two components only, is fairly simple if one keeps an eye on the S.E. : D.C.P. ratio. Let us balance oats with beans :

1 part oats supplies	60	units	S.E.	and	7·5	units	D.C.P.
1 part beans supplies	66	,,	,,	,,	20	,,	,,
2 parts mixture supply	126	,,	,,	,,	27·5	,,	,,

Now $\frac{126}{27{\cdot}5} = 4{\cdot}6$, approximately, and the mixture is relatively a little rich in protein.

2 parts oats supply	120	units S.E.	and	15	units	D.C.P.
1 part beans supplies	66	,, ,,	,,	20	,,	,,
3 parts mixture supply	186	,, ,,	,,	35	,,	,,

The ratio $\frac{186}{35}$ is about 5·3 and hence is a little low in protein.

3 parts oats supply	180	units S.E.	and	22·5	units	D.C.P.
2 parts beans ,,	132	,, ,,	,,	40	,,	,,
5 parts mixture ,,	312	,, ,,	,,	62·5	,,	,,

The ratio $\frac{312}{62\cdot5}$ is practically 5 and hence is balanced for milk production. As the arithmetic shows, the mixture will have an S.E. value of $\frac{312}{5}$ or 62·4 per cent and a D.C.P. value of $\frac{62\cdot5}{5}$ or 12·5 per cent.

The requisite number of pounds of the mixture required per gallon of milk can readily be worked out, thus :

62·5 lb. S.E. are supplied by 100 lb. mixture

2·5 ,, ,, ,, ,, ,, $\frac{2\cdot5 \times 100}{62\cdot5} = 4$ lb.

Hence one example of a simple binary milk production mixture is

3 parts of oats to 2 parts beans (*a*)

By a similar process of trial and error we can work out the values for barley (S.E. 71, D.C.P. 6·5) and ground nut (S.E. 70, D.C.P. 39) and show that

3¼ parts barley will balance 1 part dec. groundnut (*b*)

Maize and soya on the figures quoted earlier can be balanced at

3¼ parts maize meal and 1 part soya bean meal (*c*)

Since (*a*), (*b*) and (*c*) are each balanced, it follows that

(1) a blend of all three mixtures will give a balanced ration, i.e. 3 parts oats, 3¼ parts barley, 3¼ parts maize, 2 parts beans, 1 part groundnut and 1 part soya bean meal.

(2) a balanced blend will still result by taking integral parts of each mixture, provided the ratio of the separate ingredients of the mixture is maintained. As examples :

oats : beans at 3 : 2
or 6 : 4
or 12 : 8
barley : groundnut at 3¼ : 1
or 6½ : 2
or 13 : 4
maize : soya at 3¼ : 1
or 6½ : 2
or 13 : 4

Thus we still have balanced mixtures if we use, say, 1 part of group (*a*), 2 parts of group (*b*) and 4 parts of group (*c*) giving the final ration as

3 parts oats
2 parts beans
6½ parts barley
2 parts ground nut
13 parts maize
4 parts soya

For illustration we have selected cereal and protein foods in pairs, oats and beans, barley and groundnut, maize and soya. But we are not compelled to adopt this particular pairing arrangement. We could equally pair any of the protein foods with any of the cereals and by the appropriate calculations arrive at the necessary balances.

It follows from this that we have an almost infinite number of possibilities of making balanced rations from these six ingredients alone. The great advantage of thinking and working in terms of S.E. : D.C.P. ratios is that rations can be adjusted within a very wide range of conditions, paying particular care to both availability and prices.

Balanced Foods. We have still to mention the use of the "balanced" type of food. This is easy, because these foods can be added to any of the mixtures within reasonable limits and proportions without upsetting the balance appreciably. As an example, 3 parts of oats balance 2 parts of beans : if we add to this mixture one or two parts of palm kernel cake or bran we do not appreciably change the balance. The value of a mixture of 6 parts oats, 4 parts beans, 1 part palm kernel and 1 of bran can be calculated thus :

	S.E.	D.C.P.	
6 oats	360	45	
4 beans	264	80	
1 palm kernel . . .	73	17	
1 bran	45	10	
12 parts mixture . . .	742	152	
1 part mixture . . .	61·8	12·7	(Ratio about 4·87)

This mixture fed at 4¼ lb./gallon will meet the requirements of milk production.

The only other factor to be considered is the need for dairy minerals, which are usually added at a level of 2½ to 3 per cent. (It is a useful practical tip to remember that a 2½ per cent usage amounts to ½ cwt. in a ton of mixture.)

MAINTENANCE NEEDS

We have already seen that maintenance needs vary with liveweight. Such needs in cattle are normally met wholly or in part with "bulky" foods, using this term in the sense of relatively low nutritive value per unit weight. Bulky foods as thus defined may include the coarse fodders, such as hays and straws, characterised by fairly high fibre contents ; and the succulent foods, which although digestible have a low nutritive value because of their high moisture content. It is uncommon for a single bulky food to be made responsible for maintenance needs and usually bulky foods are used in combinations of at least two, e.g. hay and roots, silage and straw, and so on.

Half-maintenance Units. From the practical point of view there is much to be said for regarding maintenance foods in terms of *half-maintenance* units, since usually at least two foods are used to provide the maintenance part of the ration. For the average adult animal weighing between 9 and 11 cwt., the S.E. requirements for maintenance lie between 6 and 7 lb. daily. Consequently, half-maintenance foods supply between 3 and 3·5 lb. S.E. and the following provide some typical examples. There is also a maintenance need for protein, and the table indicates whether the allowances of foods suggested are adequate for that purpose.

TABLE 7

HALF-MAINTENANCE RATIONS

Quantity and Type of Food.	Approx. amount of Dry Matter (lb.).	Protein in excess of, or deficient for, ½M.
10 lb. medium hay	8½	o
35 lb. kale	5	++
40 lb. beet tops	6	+
50 lb. mangels	5	−−
40–50 lb. low protein silage . .	8–10	+
30–40 lb. high protein silage . .	6–8	+ to ++
16–20 lb. oat or barley straw .	14½–17	−−
5–6 lb. oats	4½–5	o
4½–5 lb. barley	4–4½	o
5–6 lb. sugar beet pulp . . .	4½–5½	−
7 lb. bran	6	+

It is inadvisable to use together two foods that are both deficient in protein, e.g. mangels and straw. Protein surpluses do not constitute a problem, but the point is worth taking that where protein surpluses exist with the dairy cow it may be possible to obtain the first gallon of milk by the use of cereals only. For example a ration of 10 lb. hay and 35 lb. kale with 4 lb. oats or barley can provide adequately for the needs of maintenance and the first gallon of milk.

The comparative figures for the amount of dry matter provided by these various half-maintenance rations are of value when high yielding cows are being rationed. Such cows have naturally a large need of concentrates, and it is important that the maintenance rations shall not be too bulky if all the necessary food is to be consumed. A low-yielding cow might derive all its maintenance needs from 20 lb. medium hay, amounting to 17½ lb. dry matter intake. Reduction in the bulk of the maintenance foods to 13½ lb. dry matter is obtained from 10 lb. hay and 35 lb. kale *or* 50 lb. mangels. A further reduction can be obtained by using 5 lb. hay (M/4) and 75 lb. mangels (3M/4) giving a daily dry matter intake of under 12 lb. The maintenance ration could be further concentrated by using 8 lb. beet pulp (3M/4) and 20 lb. beet tops (M/4) (10 lb. dry matter intake), though normally it is inadvisable to reduce the long roughage intake below 5 lb. per day, because of the danger of low butterfat content in the milk.

These rations provide examples of how to set about rationing problems, although it is always advisable to make full calculations to ensure that the stated requirements of animals are met. Bulky foods are seldom individually rationed but are given on a herd basis, so that there is every possibility that the greedy feeder may get more than its fair share. Intelligent rationing must go hand-in-hand with milk recording and careful attention to the production behaviour of each individual cow. Whereas some degree of overfeeding may not significantly raise the production of a naturally low-yielding cow, the effects of underfeeding are soon seen in the production levels of the higher yielders. Once again it is important to stress that scientific rationing must go hand in hand with the art of the stockfeeder, who quickly learns the individual habits of each cow.

The maintenance needs of cattle have been worked out under conditions of stall feeding in reasonably equitable environments. Where animals are exposed to cold, wet and unpleasant conditions, maintenance requirements must necessarily increase to an extent that is scientifically unpredictable. Maintenance needs must also increase when animals are turned out to grazing, because the extra energy of locomotion has also to be considered. Arbitrary assessment of those needs have been made to the extent of an extra 1 lb. S.E. per day for maintenance even under conditions of good grazing, and of 2 or 3 lb. extra when grazing is sparse and scanty. Unsatisfactory levels of milk production in cows calving in the autumn and lying out by night under chilly conditions can often be attributed to increased maintenance requirements in such circumstances.

RATIONS FOR FATTENING

Broadly the same principles apply to the feeding of fattening animals as for milk production, or indeed any other form of production. The maintenance needs of the animal are the first charge upon the food and the surplus nutrients in the food are available for fattening. Formerly little attempt was made towards serious fattening until a bullock was two or more years of age and after it had undergone a " store " period of either remaining stationary in liveweight or else gaining very slowly. The average bullock was usually about 9 cwt. before fattening in earnest was carried out and the greater part of its muscle and bone growth had then been achieved. Fattening consisted essentially of laying on fat both internally and within and around the muscles with the achievement of a final liveweight of upwards of 12 cwt.

With changes in the public taste favouring smaller and leaner joints, lower liveweights were achieved with animals that were still growing, in the sense of laying down muscle and bone, as well as fattening. With this came the restriction or cutting down of the long store periods formerly given ; in effect this means that the animal intended for fattening needs either a fairly high, or a highly nutritious, diet throughout its much abbreviated life.

Existing scientific standards for growth and fattening for animals under about 6 cwt. are far from being accurately based, but present-day trends obviously demand higher levels of protein and minerals for the growing, fattening animal than were necessary when the animal was much more mature before intensive fattening began. At one time it was thought that the scientific requirements for protein in fattening bullocks were unduly generous, but with modern trends for earlier finished animals it would seem unwise to attempt any reduction of the protein. Accordingly, in attempting to lay down requirements, the feeder should ensure that the total daily intake of digestible protein for maintenance and fattening does not fall below at least 1¼ lb. daily per animal.

The amount of starch equivalent required per lb. of liveweight increase is of the same order as for a gallon of average milk, about 2·5 lb., and for practical purposes this seems the best figure to work to. Further, the range of possible liveweight increase is much less than that of the range of milk production with the modern dairy cow, whose yields may vary from one to ten gallons at different stages of lactation. A liveweight increase of about 1 lb. per day (i.e. ¼ cwt. per month) is virtually a " store " standard of performance, and in present circumstances 2 lb. per day can be regarded as a minimum ; 3 lb. per day is fairly intensive fattening, and figures of 3½ or 3¾ lb. can be looked upon as very intensive.

The fattening animal of today is relatively small and it has a correspondingly smaller appetite ; this means that its diet will have to contain a higher proportion of concentrates and a lower proportion of the more indigestible bulky foods such as straw that were formerly fed to fattening animals. In effect this means some concentration of the maintenance ration as well.

Calculating a Fattening Ration. If we take as an example the needs of an 8 cwt. bullock putting on about 2½ lb. liveweight increase we have to supply, within an appetite capacity of about 20 to 24 lb. dry matter, a diet providing

For maintenance	5·5 lb. S.E.
For 2½ lb. L.W.I. (2½ × 2·5) . .	6·3 lb. S.E.

or about 11·8 lb. S.E. which should include at least 1·25 lb. digestible protein.

Let us suppose we have available limited quantities of medium hay, a good supply of kale to be followed by mangels, plenty of barley, some sugar beet pulp ; and that we can purchase some oil seed cake.

A ration of about 4 lb. hay (quarter-maintenance) and 50 lb. kale (¾M) will provide about 5·7 lb. S.E. and 0·8 lb. digestible protein within a 10½ lb. dry matter intake.

This leaves the more concentrated part of the ration to provide just over 6 lb. S.E. and another 0·5 lb. digestible protein within the compass of a further 10 lb. or so of dry matter. A mixture of 6 lb. crushed barley and 3 lb. sugar beet pulp will supply 6·1 lb. S.E. and about 0·55 lb. digestible protein in a bulk of 8 lb. dry matter. Thus the requirements are met and any necessary balance of appetite can be supplied by offering some barley straw for the bullock to pick over. No recourse has had to be made to additional purchases of protein, but the kale has contributed more than half the total protein needs.

When the kale is finished and has to be replaced by mangels, it would take over 70 lb. of the latter to furnish the same amount of S.E. as the kale, and the joint contribution of hay and mangels to the protein needs is now only about 0·4 lb. digestible protein. The barley and sugar beet pulp as before supply the necessary extra S.E. but only 0·55 lb. digestible protein, leaving at least a further 0·3 lb. protein in deficit The replacement of 1 lb. barley by 1 lb. of ground nut cake would remedy the deficiency without any change in the supply of S.E.

In practice one would probably make up a mixture of 5 cwt. barley, 3 cwt. pulp, 1 cwt. groundnut cake and 21 lb. dairy minerals, and feed 9–10 per head daily. This would guard against the possibility that individual animals fed the kale or mangels might fail to get their full share of the bulky food when a yard of bullocks is being group-fed.

Rationing with Self-feed Silage. A second example sets a different type of problem. The same types of bullocks are to be self-fed on a medium quality grass silage through the winter. Cereals, sugar beet pulp and oil cake are available as before.

First of all we have to assess the probable intake of silage. As a trial, we assume an average daily consumption of 50 lb. silage (20% D.M., 9% S.E. and 1·2% digestible protein). This would account for 10 lb. dry matter intake with 4·5 lb. S.E. and 0·6 lb. digestible protein, leaving the concentrated food to supply 7·3 lb. S.E. and 0·65 lb. digestible protein.

The mixture of 5 cwt. barley, 3 cwt. pulp and 1 cwt. ground nut (plus minerals) has an S.E. value of 67 per cent with about 9·5 per cent digestible protein (see p. 573) : 11 lb. of this supply 7·4 lb. S.E. and just over one pound digestible protein in slightly under 10 lb. dry matter. On the assumption that the bullocks would eat 50 lb. silage in addition to this level of mixed concentrates, the needs for a 2½ lb. liveweight increase are fully met, with a generous surplus of digestible protein. Omission of the ground nut from the mixture and its replacement by barley would lower the intake of digestible protein from the 11 lb. concentrates from 1·04 lb. to 0·66 lb., giving a total protein intake from silage and concentrates combined of about 1·25 lb., a marginally adequate figure. Where such a high level performance is being demanded of the bullocks it is probably not worth the risk of being marginal in respect of protein, and in practical terms it would therefore seem best to adhere to the original 5 : 3 : 1 mixture suggested above.

Rations for Other Livestock. Further information about the feeding of horses, cattle, sheep, pigs and poultry is given in Chapters XIX, XX, XXI, XXII and XXIII.

PROTEIN EQUIVALENT

In many books the protein needs of ruminant animals are often expressed in terms of *protein equivalent*, and some explanation is called for. The crude protein content of a food is determined by measuring its total nitrogen content (by the Kjeldahl procedure) and arbitrarily multiplying this by $\frac{100}{16}$ or 6·25 on the assumption that proteins on average contain about 16 per cent nitrogen. The nitrogen in a feeding stuff is normally present to a great extent as true protein. which can actually be precipitated by copper salts under specified conditions, and to a much lesser degree as simpler nitrogenous compounds called, loosely and incorrectly, " amides ". Consequently,

Crude Protein = True Protein + " Amides ".

These simple nitrogenous compounds have little or no value as a source of nitrogen to pigs and poultry, but with ruminants (cattle, sheep) the bacteria in the rumen are able to break up these simple compounds and utilise the nitrogen by building it up into their own bacterial substance (see p. 504). As these bacteria are swept along by the food into the true digestive portions of the alimentary tract, they become digested to a variable degree and the ruminant body is able to make use of these digestive products. The nature of the faeces which are the subject of bacterial attack, breakdown and synthesis in parts of the large intestine is such that it is impossible to produce a realistic figure for the true protein content of the faeces, and hence the degree to which true protein is digested cannot be accurately determined.

The problem has been solved in a rather arbitrary manner by assuming that the degree of utilisation of the " amides " is half that of a corresponding amount of true protein. In effect

% digestible crude protein = % digestible true protein + % digestible " amides ".

Since the amount of digestible true protein cannot be accurately assessed, the assumption is made that the " amides " present in the food are fully digested and they are accorded half the " protein worth " of a corresponding amount of true protein. Thus the " protein equivalent " of a food is taken to equal the undeterminable percentage of digestible true protein plus half the " amides ".

Now " amides " = analytical crude protein less analytical true protein (on the food): and % digestible true protein = % digestible crude protein — " amides ". Thus

= % digestible true protein + ½% " amides "
PROTEIN EQUIVALENT = % digestible crude protein — % " amides " + ½% " amides "
= % digestible crude protein — ½% "amides "
= % digestible crude protein — ½ (analytical crude protein–analytical true protein)

A numerical example will help to illustrate. The analysis of a food showed a content of 8 per cent crude protein and 6 per cent true protein, hence 2 per cent " amides ". On carrying out a digestibility trial with such a food on sheep, the level of digestible crude protein was found to be 5 per cent.

Now Protein Equivalent

= % digestible crude protein — ½% " amides "
= 5 — (½ × 2)
= 5 — 1
= 4%

Putting it another way, since % digestible true protein = % digestible crude protein — % " amides," and since it can be shown by mathematical calculation that protein equivalent = ½ (% digestible crude protein + % digestible true protein) the equation becomes

$$\begin{aligned}\text{Protein Equivalent} &= \tfrac{1}{2}\,[5 + (5 - 2)]\\ &= \tfrac{1}{2}\,[5 + 3]\\ &= 4\%,\ \text{as before.}\end{aligned}$$

Protein Equivalent is usually defined as half the sum of digestible crude protein and digestible true protein, but as the latter figure is not directly determinable it seems better to accept the definition of Protein Equivalent as

% digestible crude protein — ½ (% crude protein — % true protein)

all components of which are actually determinable.

The numerous assumptions in the use of the term protein equivalent make its exact evaluation a matter of considerable doubt. Nevertheless it has achieved a wide popularity as a paired term with starch equivalent.

For practical purposes there is usually very little numerically between protein equivalent and digestible crude protein, except with certain roots where the smaller proportion of the nitrogenous material present is in the form of true protein and the major proportion as "amides". Swedes, for example, contain about 1·3 per cent crude protein but only 0·5 per cent true protein and hence 0·8 per cent "amides". The level of digestible crude protein is 1·1 per cent. but the protein equivalent

$$= 1{\cdot}1 - \tfrac{1}{2}(1{\cdot}3 - 0{\cdot}5) = 1{\cdot}1 - \tfrac{1}{2}(0{\cdot}8) = 0{\cdot}7 \text{ per cent.}$$

The practical significance of the difference is small, but the appreciably lower protein equivalent value compared with that of digestible crude protein does tend to underline the fact that the greater part of the nitrogen in swedes is in non-protein form.

Chapter XIX

HORSES

THE HORSE AS A SOURCE OF POWER

THE disappearance of the working horse from so many of our farms is a matter of great regret to many people. Yet it must be recognised that a minor revolution in power resources has taken place on British farms since the late nineteen-thirties. In 1939 there were nearly 12 working horses to every tractor on United Kingdom farms, but by 1958 the number of tractors (including horticultural types) was roughly five times the number of working horses in the United Kingdom.

The horse today is used little for cultivation work, but much more for the odd carting work on farms. Tractors enable farmers to push ahead with cultivations and other field work when the weather is suitable, and can be worked at higher speeds and for much longer hours than horses, thus enabling the farmer to get through rush spells of work. However, on many farms there is a good deal of carting that can be done more economically by horses than by tractors, particularly where there is much standing while trailers are loaded or unloaded. Carting loads of hay or straw into yards for cattle, taking a load of kale or roots to cows on pasture, carting food and water to folded hens or pigs or to out-lying groups of stock, moving fencing materials to where they are required—all these and many other similar short-distance carting jobs can be conveniently done by the horse, leaving the tractor free for heavier work or long-distance haulage, thus avoiding loss of valuable field time.

Some farmers believe that during the harvesting of potatoes, sugar beet and other roots, horse transport is cheaper than any other method. At root harvest in the autumn the land is often soft and wet and horses are particularly valuable for carting under these conditions. On soft land or on wet, muddy and slippery farm roadways the horse can still move a load whereas a rubber-tyred tractor tends to spin its wheels and dig itself into the mud. Such conditions are often encountered during the carting of sugar beet and other roots in the autumn. For this reason many horses are still found in the arable areas of the country, particularly where sugar beet and potatoes are grown on a considerable scale, e.g. the Fens, the silt lands of Lincolnshire, and the Lothians. In such areas many farmers keep their horses primarily for carting off roots in the autumn. Others may buy in working horses specially for the root harvest.

The horse is a very flexible form of power, and can be used as a single unit, as in carting, or coupled with one or more other horses to make a team for heavier work. On heavy land arable farms horses are particularly useful as they can often work on the land when it is too wet for tractors, especially wheeled types. This often happens in the late autumn, and frequently in spring it is possible to do a light cultivation or distribute fertiliser on fields which are just dry on top but wet below, conditions in which tractor wheels produce considerable puddling below the surface.

Depreciation on farm tractors is high, since their average working life is short compared with horses, which can have a long working life and a low rate of depreciation ; in fact a horse appreciates in value whilst growing up to about six years of age. Horse replacements can be bred and reared on the farm, but tractor replacements must be purchased. Also the food for horses, chiefly oats and hay, can be home-grown whereas all tractor fuel and lubricating oil must be bought, thereby increasing the cash expenditure of the farm.

Few small farms today keep any horses, and the much reduced horse population of this country is mainly distributed over the larger arable and mixed farms.

TYPE OF FARM HORSE REQUIRED

The type of horse required for working on farms today is an active, clean legged one, a straight mover and a good worker ; he must be staunch in the collar, hardy, thrifty and docile, one that can be kept in good health and condition with the minimum possible attention and one that will wear well. When all the heavy work of the farm, and indeed some heavy haulage work in towns, was done by horses, size and weight were of first importance. Today, however, the need for tremendous weight in farm horses has largely disappeared and a strong, active but docile horse is required. As most horses have to be managed by inexperienced workers, especially in carting, they must be docile and easily broken to work.

The height of the ideal heavy draught horse should be from 16 to 17 hands (height is measured at the withers along a vertical line falling just behind the forelegs, and is expressed in hands, one " hand " being 4 inches). The body should appear broad and thick when viewed from both front and rear, and should give the impression of depth in side view. If the depth through the heart girth is equal to the length of foreleg, then the animal will have that low-set appearance which is so desirable, bringing the weight close to the ground, and enabling it to be used to the best advantage. A well-proportioned body combining substance with quality is required, quality being indicated by the character of the bone, tendons, head, skin and hair.

The bone should be flat and smooth, hard and dense, and the joints clean and well defined. Flat bone is much harder and more durable than round bone, and an indication of this feature is obtained by examination of the cannon bone. All joints must be clean and well defined. The tendons, particularly those at the back of the cannon bone, should be well defined, and there should be no filling between the tendons and the cannon.

In all classes of stock the head is an indication of quality and should show character. It should be lean, cleanly chiselled, with large prominent and expressive eyes, and thin lips.

The skin should be mellow and elastic to the touch, covered with fine lustrous hair, and the " feather " (i.e. the hair on the legs) should be fine and silky and present only in very small amount.

The old saying, " no foot, no horse " indicates the prime importance of good feet in a heavy draught horse. Large, round feet, uniform in size, are required. They should be neither thin nor flat. The soles should be concave, with a well-developed frog, the heels wide and the slope of the hoof parallel with that of the pastern. The quality of the horn is very important ; it should be hard, tough and dense and free from seams or cracks.

Good movement in working horses is essential, and the farm horse must be able to walk well, for most of his work is done at this pace. The action should be free, with a long and powerful stride, the limbs being moved forward in a straight line. All the joints should be well flexed when the horse moves, both when walking and trotting. Although little work is done at a trot by heavy horses, trotting gives a good indication of the horse's movement, for a horse that can trot well is generally a good walker.

A good draught horse must be "sound in wind and limb ". In theory this means that it must be " free from vice and disease ", but in practice a sound horse is one that has no defect which in the opinion of a veterinary surgeon is likely to interfere with its working ability.

BREEDS OF FARM HORSES

There are four breeds of heavy horses in this country :

Shire
Clydesdale

Suffolk
Percheron

Many types of ponies and cobs are used for light trotting work on farms and will be considered at the end of this section.

The Shire. This breed has been bred for centuries in the rich fen districts of Lincolnshire and Cambridgeshire and in many western counties. It is the largest breed of horse in the world, stallions commonly measuring 17 hands, and also the heaviest often weighing from 17 cwt. to a ton. It combines great strength with docility, and is a good mover. The commonest colours are bay and brown, though black is found and grey has become popular in recent years (Plate XXXIIIA).

A characteristic of the breed is the quantity of hair or " feather " carried below the knee and the hock, not only at the back of the legs but also at the sides. This feather made the limbs appear very large and strong, and was very showy, but it is extremely difficult to keep clean especially in muddy conditions on heavy land. Nowadays breeders are aiming at a horse with the minimum of feather to meet changed conditions, especially of fewer horsekeepers and higher labour costs. As one means of breeding cleaner-legged horses the Shire Horse Society operates a grading up scheme, whereby Shire-Clydesdale cross females may be entered in a supplementary register and their female progeny by a registered Shire stallion are eligible for full registration in the Shire Stud Book.

The Clydesdale. Most heavy horses in Scotland belong to this breed. It is rather smaller than the Shire, the average height of stallions being about 16½ hands, and is distinctly lighter. Clydes-

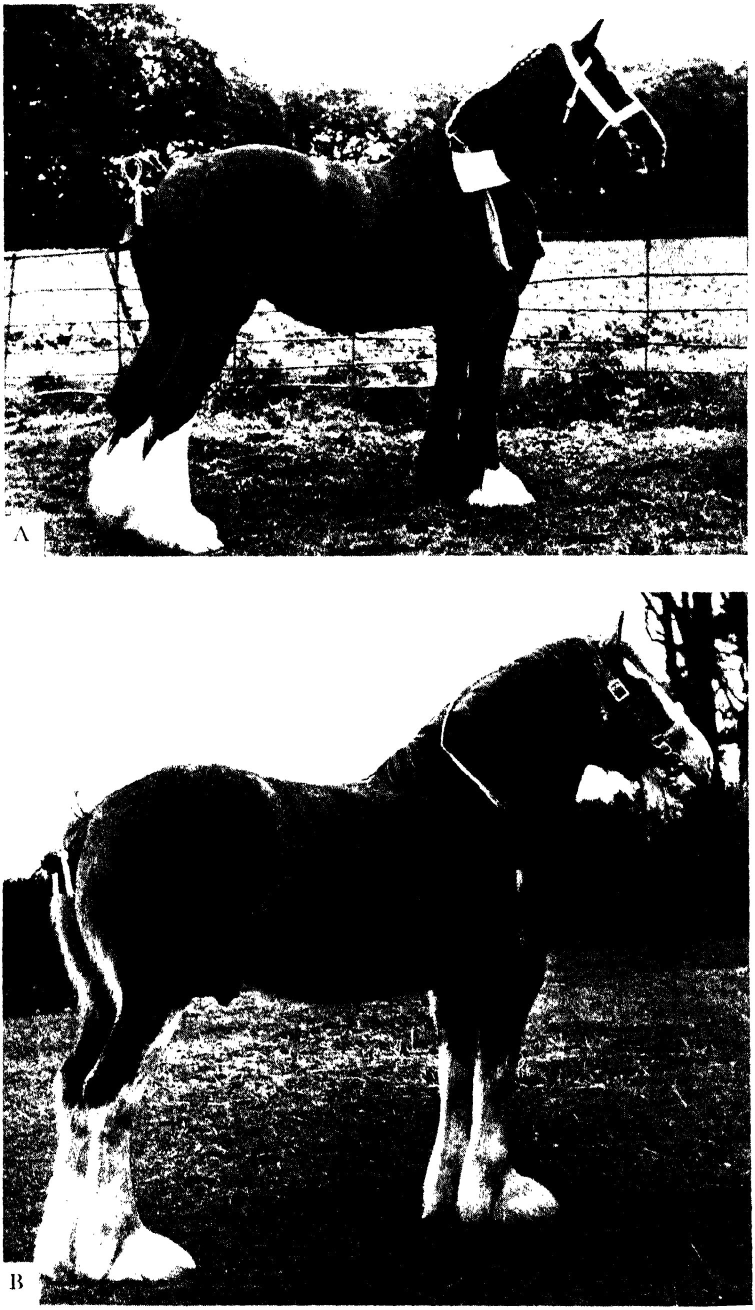


PLATE XXXIII

A. Shire Mare

B. Clydesdale Stallion

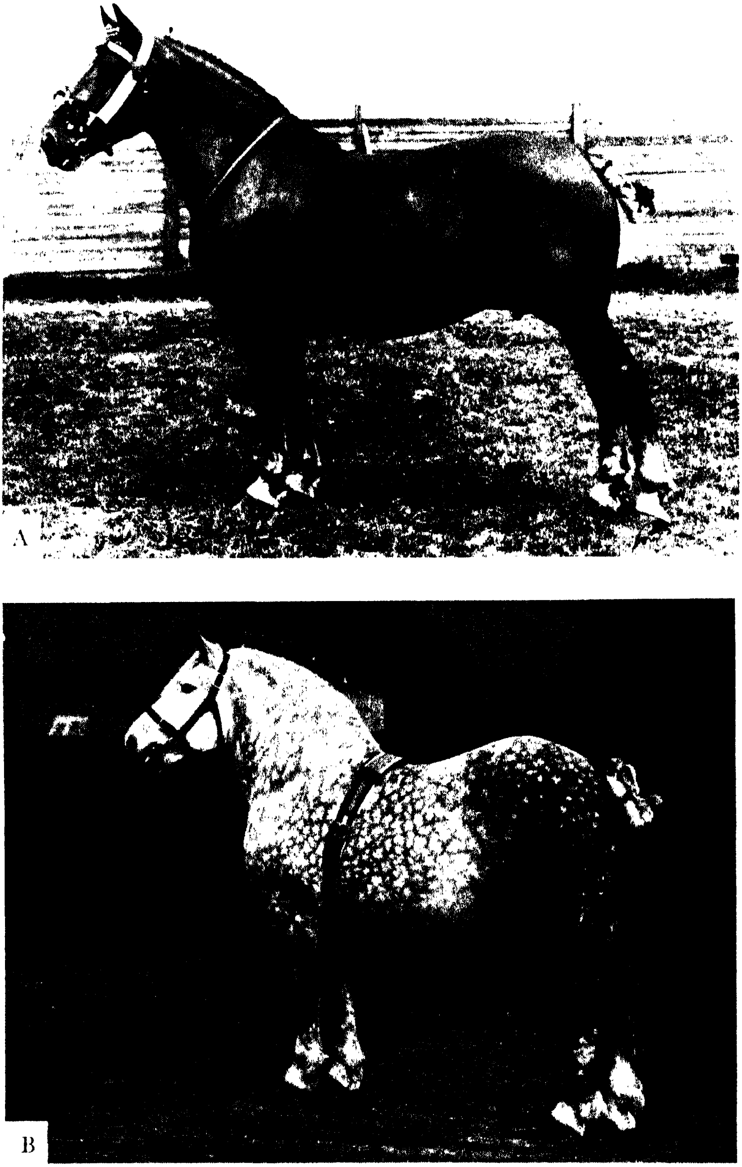


PLATE XXXIV

A. Suffolk Mare

B. Percheron Stallion

dales are not so well ribbed as Shires, not as deep bodied and rather longer legged. To some farmers they appear a little short of middle. The breed, however, is characterised by great activity, good movement with a very straight action, and much less feather than is found in the Shire, there being only a fringe of fine silky hair confined to the back of the leg (Plate XXXIIIB).

The Suffolk. The Suffolk is of similar height to the previous two breeds, but is distinguished by its chestnut colour and absence of feather on the leg. The deep thick body and the wonderful natural condition are characteristic of the " Suffolk Punch ". The breed is rightly famous for its hardiness, longevity, docility, pluck and willingness to work. These valuable features coupled with its clean legs make the Suffolk a very good farmer's horse (Plate XXXIVA).

In the past Suffolks have not been popular with town buyers owing to defective feet ; these were inclined to be pinched at the heels, and gained slope at the expense of being shallow over the bars. Also the horn was of poor quality, being rather brittle. Much attention has been paid to the feet in recent years, and special " feet classes " have been arranged by the Suffolk Horse Society at its shows and sales to encourage this. There is no doubt that the modern Suffolk has a much better foot than its predecessor of twenty years ago.

The Percheron. This breed of heavy horse is a native of the La Perche district of France and was first introduced into Great Britain at the end of the 1914–18 War. It may be called the heavy draught horse of the world, for it outnumbers any other breed.

The Percheron is one of the most active of draught breeds, and compares with the Suffolk for hardiness, longevity, thriftiness and docility. It is medium in size, though many individuals attain great scale, and the tendency in this country is to breed a heavier type. The Percheron is a strongly built horse, with very muscular forearm and quarters, with clean legs and standing squarely on excellent feet. The typically hard blue horn of the feet, the well-set joints and flat flinty bones of the Percheron horse have made it an ideal draught horse in all parts of the world. Its docility and ease of handling are valuable assets today (Plate XXXIVB).

The Percheron stallion is very prepotent, and because of the popularity and excellent type of half-bred Percherons produced by crossing on mares of other breeds, a Supplementary Register was established in 1941 so that it is now possible to " grade up " stock and in three generations they become eligible for full registration. This Register was set up mainly to supply a growing demand for clean-legged horses of Percheron type.

Ponies and Cobs. Apart from the typical heavy draught horses on British farms, a smaller number of lighter horses is used. Where a large flock of sheep is kept, a cob and light float are often allocated to the shepherd for transporting small lots of feeding-stuffs and hay to the various lots of sheep. A cob is particularly useful for carting food and water to folded flocks of poultry and to tethered sows which may be at some distance from the homestead. Many farmers, especially in hilly districts, use a cob or pony to ride round their farms, visiting stock, and men at work.

Ponies vary in height from as little as 8½ hands to about 14 hands, and the breeds of pony native to these islands include :

Dales
Fell
Dartmoor
Exmoor
Highland
New Forest
Shetland
Welsh

Though these breeds differ considerably in size and appearance, they have certain features in common and probably originated from a common stock. They are all very hardy, able to live through severe climatic conditions and to thrive on inferior food. All ponies combine considerable strength with small size, and are active and sure footed.

The cob is not a breed of horse but a type, being short legged and standing about 14 hands high. It is bigger and carries more bone than most ponies. Cobs are bred in various ways, but most combine a cross of a heavy breed of horse with a pony breed.

FEEDING AND MANAGEMENT OF WORKING HORSES

Feeding and Grooming. The horse, whether a heavy horse or a cob, is essentially a working animal. Feeding must therefore be determined according to the type and duration of the work required at any one time. The basis of rations for working horses is digestible carbohydrate food, the main source of energy for muscular work, and a small amount of protein is necessary for the repair of worn tissues.

A suitable winter ration for a heavy farm horse doing medium work would be :

Oats—12 lb. per day = 84 lb. per week (i.e. 2 bushels per week)
Hay—16 lb. per day = 112 lb. per week.

Seeds hay (" hard hay ") is preferable to soft meadow hay. Where oat straw of high quality is available it may replace all the hay.

Custom and experience indicate that oats form the most suitable concentrated food, but some of the oats may be replaced by other foods to cheapen the ration. The total quantity of corn given at any season should be regulated by the amount of work to be performed, and every increase in work should be accompanied by an increase in the quantity of corn, and vice versa. Nothing is more likely to cause colic than to feed a full corn ration to an idle horse.

It is impossible to define light, medium or heavy work, and in practice the horse owner watches the condition of his animals, and adjusts the quantity of corn accordingly. If an animal shows signs of losing flesh the oats are increased, but if it tends to put on fat the corn ration must be reduced. On no account should a working horse be allowed to become fat ; a fat horse is not a fit horse, and while it is necessary to maintain horses in good condition, fatness is a disadvantage.

A horse has a small simple stomach and hence all foods must be fed in a fairly concentrated form. All corn should be rolled or cracked as this leads to more efficient utilisation than is obtained when grain is fed whole, and the corn should be fed with chaff to prevent bolting and to ensure mastication. A small allowance of roots or other green foods helps to keep the bowels of the horse in good working order. All horses should have access to a lump of rock salt ; this is important in the maintenance of good health, and particularly valuable to keep the kidneys working well. The importance of an abundant supply of clean water cannot be over-emphasised ; water should always be given before food, especially when horses return from work. The quantity of water may be reduced when horses are hot from heavy work. It is important that feeding should be at regular intervals, preferably moderate meals at short intervals on account of the nature of the duties and the characteristics of the digestive system of the horse.

During the summer months horses are normally turned out to grass at night, and no hay is fed ; a small allowance of corn is given according to the amount of work being done.

" A good grooming is worth a feed of corn " is an old adage which emphasises the importance of cleaning working horses. Thorough grooming after work entails cleaning the coat well with a curry comb to bring the dirt well out from the skin, and then giving a good brushing with a hard brush. Finally the horse may be rubbed down with a cloth. Before work, horses are normally brushed only. Hairy-legged horses must be kept clean otherwise a trouble known as " grease " (a bacterial infection of the skin of the legs) may result.

Housing. The stable should be spacious, well ventilated, light, well drained and free from draughts. This is especially important where horses lie in the stable at night for part or all of the year. In the eastern counties of England horses are commonly housed at night during the winter in semi-covered straw yards, the stable being used only for feeding the corn ration, for grooming and for harnessing. Under this system a much less elaborate stable is required, much labour is economised and the horses thrive well, suffering less from cold and chills than if left in the stable overnight.

During the summer months horses are usually turned out to grass at night. Horses are notoriously bad grazing animals, dung always being dropped on selected parts of the field while other parts of the field are over-grazed. This gives rise to the characteristic patchy appearance on pastures grazed entirely by horses, and fields should not therefore be stocked by horses exclusively.

BREEDING AND REARING FARM HORSES

Farmers regard their horses in a variety of different ways. They may be kept simply as a means of performing certain tasks in the cheapest way possible, or they may be regarded not only as a means of performing certain work but also as a definite profit-earning section of the farm. In the first case, it is usual to keep a regular team of working horses of all ages, and the wastage, which continually occurs through age, accident or disease, is made good either by purchasing young horses or by breeding a sufficient number of foals each year to meet the requirements of the farm. In this way the buying and selling of horses is reduced to a minimum and every horse is retained on the farm for the maximum period. Some farmers, particularly those with a small amount of available capital, adopt the practice of using only old or slightly unsound horses for land work, because such horses, though quite unfit for road work, will work reasonably well on the land and may be purchased at very low prices. Consequently the capital locked up in working horses is reduced to a minimum, and though the wastage is bound to be high in such a team and the efficiency of the team may at times be reduced, the practice is justifiable in certain circumstances.

Farmers who expect their horses to do a certain amount of the work of the farm and to earn some profit in addition may achieve their object in one of two ways—by breeding, or by buying and rearing. A few mares may be bred each year, and some of the foals used eventually as replacements for the farm teams, the surplus being sold as foals or at a later age, depending on which is the most saleable age at any one time. In this way the farm teams can be kept young and efficient, and a few surplus young horses together with a few older ones will be for sale from time to time. Usually the breeding mares are treated as working horses, and expected to earn their keep in the teams, except for the short period during the summer when they are suckling their foals. This is the most sensible and the most economic way of keeping breeding mares, for they will be kept fit by working, will usually breed more regularly as a result, and the work that they do covers the cost of their keep. Hence the foal can be treated as an extra return for the farmer.

Breeding Horses. It usually pays to use the best stallion available, even if the service fee is slightly higher. Stallions may be first used for service on a few mares at two years old, though at this age they are uncertain stock-getters. A stallion which leaves few foals as a two-year-old may be perfectly satisfactory at three years of age. Stallions are not travelled before three years old, and during the breeding season, which lasts from April till the end of June or beginning of July, a stallion may cover from 50 to 100 mares. (All stallions which travel from farm to farm for the purpose of serving mares must be licensed annually by the Ministry of Agriculture as being sound in wind and limb and of good type).

It is more desirable to breed from one good brood mare than from several very ordinary ones. A good brood mare should be long, low and wide, sound and free of grease. Tall "split up" mares do not make good brood mares, neither do light-ribbed mares.

It is an advantage to start breeding fairly early in the season, say in April, so that the mares can be weaned by harvest time and become available for work at that season. A mare which has foaled is more likely to stand to service on the ninth day after foaling than at any other time ; a mare comes into use at three-weekly intervals during the spring and summer, and may remain in season for five, seven or even ten days. Well-grown and developed fillies may be safely mated at two years old provided that they are well done and not worked during pregnancy. The more normal practice is to mate fillies first at three years of age. The gestation period is about 340 days ; the fecundity of horses is rather low, for over a period of years not more than 60 per cent of served mares prove to be in foal.

An in-foal mare is treated in the same way as any working horse up to the fifth or sixth month of pregnancy, but from that stage she will be placed in the charge of a careful man when at work and worked only in chains. It is desirable that she should work regularly right up to the time of foaling in order to keep her fit ; on no account should a brood mare be allowed to become fat, otherwise she will probably have trouble in foaling. During the later stages of pregnancy her food will be improved, straw in the ration being replaced by good hay, and the allowance of oats and bran being increased slightly.

Foaling should take place in a clean and well-disinfected loose box, in which the mare has been housed for several nights before foaling so that she is accustomed to her surroundings. Her bowels must be kept open by feeding sloppy foods, such as bran mashes, and a little succulent food if available. Immediately after birth the navel cord of the foal should be tied up and disinfected, the disinfection being continued (as a protection against joint ill) until the navel has dried up. Many foals are lost through constipation after birth ; this is indicated by switching of the tail, straddling and general uneasiness. The rectum should be washed out well with a soap and water enema and greased with Vaseline. It is important to see that the foal suckles its mother within 12 hours of birth, assistance being given if necessary.

As soon as the weather is suitable the mare and foal are turned out to grass, and the foal continues to suckle for four to six months. About a month before the foal is weaned, a ration containing crushed oats, bran and if possible a little linseed cake is fed to the mare to get her fit for working again, and at the same time the foal learns to eat corn. After weaning the foal should be run preferably with another horse in a field not previously grazed that season by horses. Here it will receive a ration of about 4 lb. per day of a mixture containing crushed oats, bran and a little linseed cake, split beans or fish meal. A little mineral supplement should be added to the ration.

Rearing Young Horses. The first winter is a critical period during the life of a young horse, and it is at this time that the horse is either made or marred. Underfeeding at this period prevents the horse from developing into as good an animal as it otherwise might do, but if done well in the first winter young horses may subsequently be treated rather roughly without suffering permanent harm.

Young horses are sometimes housed during the winter, preferably in large airy yards so that they can get some exercise as this is absolutely essential to development. Most horse breeders prefer to let their foals spend the winter in a dry, sheltered paddock, with an open shed available for bad weather and for feeding. Regular feeding with a corn ration and plenty of really good hay during the first winter is essential. Also during this time, especially if the horses are housed, their feet should be watched and kept pared down to shape. Colt foals are castrated in May, when they are about twelve months old.

During their second summer, young colts will be at grass, preferably on a field where they will not get too fat, and a field which is well watered and free from pitfalls, such as deep, unfenced ditches. From this time onwards young horses are little trouble to rear, and will live on the pastures until they are wanted for work. In the winter months they will be fed a little hay. Their feet must be pared occasionally to preserve the correct shape, and the young horses may require dosing periodically with phenothiazine to keep them free from intestinal worms.

Breaking-in Young Horses. Young horses are broken-in to farm work at the age of two to three years, depending on the type of soil on which the farm is situated and the development of the young horses. Well-grown colts can do a certain amount of useful farm work from two years old. Breaking-in is not a very difficult operation, especially if the horses have been taught to lead as foals and if they have been handled a little from time to time during the growing stages. In the first place a set of harness is put on the horse, and the horse left in a yard to become accustomed to the feel of the various parts and especially of the bit.

The next stage is to harness the horse to a small log of wood, and allow it to pull the log about ; in this way it is taught to pull, and can be taught to drive in long reins. Within a few days a young horse may be worked in chains at plough or harrow with a steady old horse or between two old horses. A young horse may require leading for the first time at work, but soon becomes accustomed to being driven in a team. It is unwise to overwork a young horse ; half a day at a time is quite sufficient at first, and it is therefore an advantage to break in two young horses at the same time. Young horses may be broken in to shaft work at three years old or just over, but on no account should the cart be overloaded, otherwise the horse may become a jibber. It will not do much work on hard roads until it is four or five years of age. When a horse is fully broken and goes well in all classes of work it is said to be " a good worker in all gears ". Horses that have been handled as foals can usually be broken into full work in chains in about three days, but those that have never been handled before may be very wild and require taming first.

Chapter XX

CATTLE

The total cattle population in Great Britain now exceeds 10 million (June 1959 Census), with 8½ millions in England and Wales and 1¾ millions in Scotland, compared with a population of some 7¼ millions at the beginning of this century. Most of this increase in the cattle population has been in respect of cattle kept mainly for the production of milk, so that today the value of milk sold off farms is twice that of meat (as beef and veal). This trend towards increasing production of milk is now slowing down and more attention is now being given to the expansion of beef production from dairy herds, involving new systems of breeding, rearing and feeding.

Of the 19 major breeds of cattle in Great Britain, we can distinguish three main groups ; *Dairy Cattle* kept mainly for milk production ; *Beef Cattle* kept mainly for beef production ; and *Dual Purpose Cattle* which have the characteristics of giving reasonable milk yields allied with fattening propensities. This classification is by no means rigid as strains within the different breeds can exhibit considerable variation.

CLASSIFICATION OF CATTLE BREEDS

Beef Breeds

- Beef Shorthorn
- Hereford
- Aberdeen Angus
- Devon
- Sussex
- Highland
- Galloway
- Lincoln Red Shorthorn

Dual Purpose Breeds

- Dairy Shorthorn
- Red Poll
- South Devon
- Welsh Black
- Dexter
- British White

Dairy Breeds

- Ayrshire
- British Friesian
- Guernsey
- Jersey
- Kerry

CHANGES IN BREED DISTRIBUTION

The first census of cattle classified by breed was carried out in 1908 by the Board of Agriculture. The changes in breed distribution since that date are illustrated in the following diagram, which refers to England and Wales : the diagram is based upon the most recent census of the cattle populations by breed carried out by the English Milk Marketing Board in 1955.

In Scotland dual-purpose cattle have never attained the popularity they have enjoyed in England and Wales and, over the same period, the relative distribution between beef and dairy breeds in Scotland has remained relatively uniform with dairy cattle now 38 per cent of the total cattle population. The relatively greater importance of beef cattle, 62 per cent in Scotland compared with 16 per cent in England and Wales, reflects the difference in the cattle economy north and south of the Border. In Scotland, with its much higher proportion of hill and upland grazings, beef cattle are the dominant cattle enterprise. The more productive lowlands are devoted to milk production, or arable farming with cattle fattening, whereas hill farms are predominantly stock rearing farms—to a less extent this is also true of Wales and South West England.

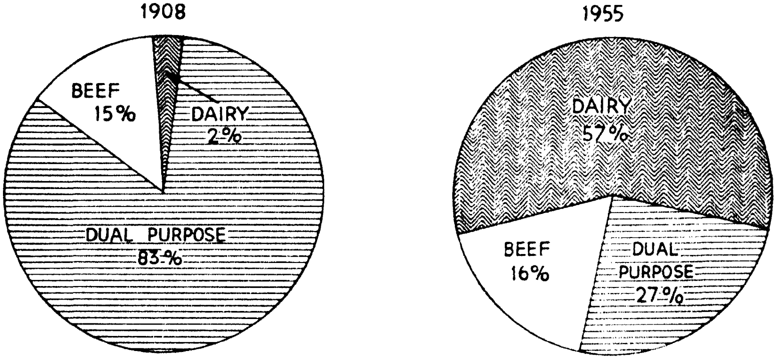


FIG. 113.—Changes in Breed Distribution, 1908–1955.

The relative numerical importance of the different breeds of pedigree cattle can be judged from the membership of the major breed societies :

MEMBERSHIP OF BREED SOCIETIES (1959)

Beef Breeds.		Dual Purpose Breeds.		Dairy Breeds.	
Beef Shorthorn .	310	Dairy Shorthorn (U.K) .	4,974	Ayrshire . . .	5,907
Hereford . .	3,316	Northern Dairy Shorthorn	597	British Friesian	13,962
Aberdeen Angus	2,910	Red Poll	1,212	Guernsey . .	2,872
Devon . . .	754	South Devon	760	Jersey (U.K.) .	5,520
Sussex . . .	275	Welsh Black	507		
Highland . .	344				
Galloway . .	772				
L. R. Shorthorn	349				

BEEF BREEDS

The Beef Shorthorn. The Shorthorn originated in the north-east of England : it owes its principal development to the Colling brothers who lived near Darlington, and whose herd was established from the best of the earliest foundation stock in 1784. Robert Culley, who was a close friend of Robert Bakewell of Dishley, made the Collings familiar with the methods of livestock improvement that in Bakewell's hands had given such good results in the development of the Leicester breed of sheep and the Longhorn breed of cattle. The Collings started their herds from existing good stocks of cattle. The bull, " Hubback 319 ", is regarded as the father of the improved Shorthorn and one of his most famous descendants was the bull " Favorite 252 ", himself a product of inbreeding. The influence of the Collings as breeders was to produce an animal of moderate size, shapely and early maturing, with well-sprung ribs, short legs and good thick hide covered with thick mossy hair. Though the cattle were thick fleshed, by modern standards they tended to be patchy in their fleshing.

Two Yorkshire men, Thomas Bates and Thomas Booth then influenced the development of the improved Shorthorn in the early nineteenth century, and this breed dominated the cattle of the country for nearly a century. Booth concentrated on the development of the beef type, whereas Bates was more concerned with the development of the dual-purpose characteristics and the dairying capacity of the breed. At this time the improved Shorthorn quickly established itself in Scotland, and in Aberdeenshire in particular where its development was largely the work of Amos Cruickshank of Sittyton. As in the case of the Colling brothers, Cruickshank was equally dependent upon the use of the prepotent sire, the greatest of which in the Sittyton herd was a bull called " Champion of England 17526 ", calved in 1859.

The Shorthorn was developed subsequently to serve the needs of beef production, particularly in the northern region of England and Scotland. A polled strain of Shorthorns is now being developed, mainly from polled Shorthorns imported from Australia.

Throughout the world, the Beef Shorthorn is still regarded as the dominant beef breed, for its type is that of a blocky animal, standing on short legs and possessing the capacity to produce a good carcase of beef. The distinguishing colours are red, white and roan (Plate XXXVa). The Shorthorn Society was formed in 1875.

The Hereford. This is a purely beef breed, for long associated with its native county. It is probable that this breed shares a common origin with the Devon and Sussex breeds, but the white face and characteristic markings originated from a cross with white-faced Flemish cattle imported to the county before 1671. The early improvement in this breed was due to the efforts of Benjamin Tomkins and his son between the years 1742 and 1815. The Tomkins selected for beef and were good judges of cattle. Thereafter the Hereford was skilfully bred and developed and was very successfully exhibited at the Smithfield Show in the first half of the nineteenth century. It is largely a grass beef breed, with the capacity to fatten readily on grass alone. Animals are bred and reared under natural conditions, the cows running on grass throughout the year and receiving extra treatment in the form of hay and straw during severe weather and at calving time. As a result the breed has been remarkably free from tuberculosis and the cows are good mothers, rearing their calves well.

Herefords are popular in North and South America and have proved themselves to be one of the best breeds for ranching purposes : they are able to resist better than most breeds the effects of shortage of water and fodder. Polled Hereford cattle are now being bred in this country, mainly from polled parent stock imported from Australia and Canada, and a separate Poll Hereford breed Society is now in being. The parent Hereford Society was founded in 1878.

In size, weight and maturity they compare favourably with the Shorthorn. Their colour is distinctive ; the face, throat, chest, legs, lower portion of the body, crest and tip of the tail are white, with the rest of the body red (Plate XXXVB). The white face is a dominant characteristic of the Hereford breed : when this breed is crossed with other breeds, the white face is a valuable quality in the scheme for colour-marking calves where such animals are destined to be reared for beef purposes.

The Aberdeen Angus. This black-coloured, hornless breed is native to the north-eastern counties of Scotland and in particular the counties of Forfar and Aberdeen. In its modern form it descends from two similar types in these counties from which it derives its name, and there is evidence of its existence in 1523. The pioneer breeder was Hugh Watson of Keillor in Forfarshire. The Keillor herd was established in 1808 and the breeding policy was moulded on the methods adopted by the early breeders of improved Shorthorns. Watson's foundation cattle were the best that he could buy and he was a good judge of cattle and a skilful breeder and feeder ; his mating policy, though not entirely favouring close-breeding, nevertheless permitted its use when circumstances justified the practice. His herd was dispersed in 1865. The second notable influence on the breed was the work of William McCombie of Tillyfour in Aberdeenshire, whose herd was founded in 1830 and dispersed in 1880. The breed's international reputation was created largely as a result of McCombie's exhibits at the International Exhibition in Paris in 1878, when the Aberdeen Angus breed won the prize for the best group of beef-producing animals. The third pioneer was Sir George McPherson Grant, whose herd at Ballindalloch in Aberdeenshire played an important part after the dispersal of the Tillyfour herd.

As a producer of high-quality beef the breed is almost perfect. It does well under confinement, keeps its form in the fattening process without any tendency to patchiness, and the finished beast is a solid mass of firm meat. The proportion of dead- to live-weight is unusually high. The breed is early maturing and produced the first two-year-old champion at the Smithfield Show. There has been a tendency recently for the breed to lose its size as a result of a show-yard craze for small animals.

The bulls of the breed are used extensively for crossing purposes for the production of quick-maturing high-class steers. These grow into good beef animals and inherit the black colour and polled character of the sire (Plate XXXVIA). The Aberdeen Angus Society was founded in 1879.

The Devon. The Devon, or North Devon as it is frequently called to distinguish it from the South Devon, is native to North Devon and Somerset and, by contrast with the three preceding breeds, is more local in its distribution. The breed derived originally from the common stock which also produced the Hereford and Sussex, and the recent development cannot be attributed to any outstanding pioneers, though the Quartly family of Molland in North Devon exercised a great influence on the breed from the beginning of the eighteenth century to the middle of the nineteenth century.

These cattle are distinguished by their rich ruby-red colour, but they are smaller in size than the preceding breeds. They are characterised by their extreme neatness, fineness of bone and evenness of fleshing. For its size the Devon is remarkably thick-fleshed and produces meat of high quality that compares favourably with that of the Aberdeen Angus. Devons make excellent grazing cattle, particularly on pastures that would not be suitable for larger breeds and their maturity is average (Plate XXXVIB). In spite of the Devon's high quality as a beef breed, only a few herds are kept exclusively for beef production, a certain amount of milk being drawn during the spring and summer. In this respect the breed is more notable for the quality rather than the quantity of produce. The Devon Cattle Society was founded in 1884.

The Sussex. This breed, which in external appearance bears a similarity to the Devon except that it is larger, is native to the county of its name, but has a popularity on the Wealden clays and the marshlands of Sussex, Kent and Surrey. Until the present century the breed was bred for draught purposes. It is one of the hardiest breeds, able to thrive under the most unfavourable circumstances and, unlike most cattle, it does not pick and choose when grazing, but will graze right through a pasture from one side to the other, taking the rough with the smooth. It will also keep itself as a good store on the poorest of pasture. Its maturity is good if well looked after and the quality of beef is equal to that of the Devon (Plate XXXVIIA). The Sussex Cattle Society was founded in 1878.

The Highland. This breed is probably descended from the aboriginal wild cattle of the country and its principal breeding area comprises the Western Highlands of Scotland and the islands off the west coast of Scotland. No cattle in the United Kingdom have preserved in greater uniformity their characteristic breed points than the Highlanders or ' Kyloes ' have done. This of itself points to their antiquity and purity of breeding. Indeed, attempts to improve them in their native environment by the introduction of alien blood have failed.

The Highland is most distinguished in its appearance, carrying a well-formed but low-set body, covered with a thick skin that produces a long growth of wavy hair. The short and well-balanced head carries horns of good length. The colour is variable, with yellow, light dun, brindle, red and black being common (Plate XXXVIIB).

The outstanding characteristic of the breed is its hardiness ; it can withstand exposure to wet and cold and can exist on scanty and poor pastures. This is the smallest of the beef breeds, apt to be somewhat nervous, and rather slow in maturing. The quality of meat is excellent and they are popular for finishing on good pastures.

The Galloway. This breed takes its name from the province of Galloway, comprising the counties of Kirkcudbright and Wigton in the south-west of Scotland. The breed has also been long associated with the counties of Dumfries and Cumberland. Their characteristics and qualities suggest that they are of considerable antiquity. Compared with the Aberdeen Angus they have a flatter poll and carry a greater length of hair on the skin, and are slower in maturing. Their colour is variable, but two pedigree types have been evolved, namely black and belted strains. (Plate XXXVIIIA).

The breed is notable for its great hardiness and is only surpassed in this by Highland cattle. In its native habitat the cattle are wintered in the open. They are excellent grazers in rough pastures but also finish well on rich land. The quality of their meat is regarded along with the Highland, as the best of all beef, having a high proportion of lean to fat, with a fine grain and rich flavour.

They are highly valued for crossing purposes. The cows are frequently mated with white, beef Shorthorn bulls, the result being the famous polled 'Blue Greys'. These are very popular cattle with both feeder and butcher, for they inherit the most valuable characteristics of both the Galloway and Shorthorn parents. The Galloway Cattle Society was founded in 1877.

Lincoln Red Shorthorn. This is a strain of the Shorthorn which has been selected for its cherry-red colour and it has been bred in its native county for over a century. The name that is associated with the early development of this type of Shorthorn is that of Thomas Turnell, of Wragby in Lincolnshire, who selected and bred only red-coloured Shorthorns. Slightly larger and coarser in the bone than the Dairy Shorthorn, they grow to a big size on the large arable farms of their native district and they have a high reputation with graziers in the East Midlands.

Of recent years a polled strain of Lincoln Red Shorthorn has been developed by Mr. C. L. Pentecost, to meet the increasing demand for polled beef cattle which fatten more readily, require less yard space per beast and suffer less damage during transit.

Although the Lincolnshire Red Shorthorn Association has maintained a separate herd book since 1935, breeders are permitted to use red bulls that are registered in Coates' Herd Book of the parent Shorthorn Society which was first published in 1822 (Plate XXXVIIIB).

DUAL PURPOSE BREEDS

The Dairy Shorthorn. The history and characteristics of the Shorthorn breed have been covered in the section on beef cattle, but the bulk of Shorthorn cattle in the United Kingdom are essentially dual-purpose animals. At the end of the last century there was a definite danger that the dairy qualities of this herd would be lost as a result of high prices offered for beef-bulls, so the Dairy Shorthorn Association was formed in 1925. The Northern Dairy Shorthorn Association, with a separate herd book, was formed in 1945.

Although the dual-purpose ideal implies the production of animals with the capacity to milk and fatten, the modern emphasis with both the Dairy Shorthorn and the Northern Dairy Shorthorn, is to develop still further the milking properties. With regard to milk yield, Dairy Shorthorns are about 180 gallons below the Friesian and 60 gallons below the Ayrshire level. The butterfat at 3·59 per cent has remained practically unchanged for the last 20 years.

These are still the most important breeds of cattle in the northern region of the United Kingdom where, in 1955, out of a cattle population of 250,000, 40 per cent are Dairy or Northern Dairy Shorthorns, and in the Mid-Western Region 30 per cent are still of Dairy Shorthorn type. The decline of the breed however, continues, but a good market prevails for calves for rearing for beef, and this is an important asset to the breed. (Plate XLII A).

The Red Poll. This breed originated in East Anglia from a cross between the Suffolk cattle with good milking qualities and the Norfolk beef animal, and became a distinctive type by the year 1846. It is still found in its greatest numbers in East Anglia but has spread to almost all counties.

The Red Poll is a medium-sized, active breed with the advantage of being naturally polled. They are probably more suitable for fattening early than at a later age because of their lack of size when mature.

Their milking properties are very reliable and the yield of milk and fat is very similar to that of the Dairy Shorthorn. Their chief weakness in the dairy sense is the lack of shapeliness of udder, but improvements have been made in this respect. Their type is also subject to variation in the absence of careful breeding (Plate XXXIXA). The Red Poll Cattle Society was founded in 1888.

The South Devon. The South Devons are the country's heaviest cattle ; cows of the breed often weigh 15–16 cwt. and mature bulls up to 30 cwt. (Plate XLIIB). It is native to South Devon, and the Guernsey is thought to have played a part in the development of the breed.

The breed is pale red in colour, inclined to be strong-boned but with a good reputation as a dual purpose animal. According to the Milk Marketing Board Census of 1955 about 24,500 cattle of this breed are kept for their milk which is very rich, often averaging 4·5 per cent butterfat. Their milk yield is not, however, as high as the Dairy Shorthorn by approximately 10 per cent.

The Welsh Black. These cattle constitute one of the most ancient breeds, and the modern breed is the result of merging several local types, but chiefly the breeds of South and North Wales, combining both milk and beef qualities. Because of hill land and lime-deficient soils, it does not attain a high standard of uniformity of milk production—yields are about 600 gallons with butterfat of 4 per cent. The most valuable characteristics of this breed are the hardiness and ability of the cows to produce good yields of milk under poor and hard conditions (Plate XLIIIA).

The Dexter. The smallest of our breeds, weighing on an average 6½ cwt. (Plate XLIIIB).

It is coloured either whole black or whole red and has good dual-purpose qualities. This breed provides one of the most interesting examples of the operation of a lethal factor. Thus when pure bred about one-quarter of the calves are monstrosities with a very large head and usually do not live very long. This condition can be avoided by mating Dexters to Kerrys.

The British White. This breed is generally polled although there are some horned types and they are spread over 24 counties. In 1954–5 the 6 officially recorded herds averaged 730 gallons at 3·97 per cent butterfat.

DAIRY BREEDS

The Ayrshire. This is the only native breed of pure dairy cattle which has originated in the United Kingdom and is native to the county of Ayrshire in the south-west of Scotland. An early improver of this breed was John Dunlop, of Dunlop in Ayrshire, but the breed was developed along its modern lines during the nineteenth century.

During the past 20 years the breed has established itself in England and Wales where 18 per cent of dairy cattle are now of the Ayrshire type.

The Ayrshire has horns that incline upwards, and colouring is in varying shades of red or brown, and sometimes black, patches on a white background. Particularly characteristic is the shapeliness and quality of the cow's udder, a type of udder which breeders would like to see more widely distributed. Calving at an average age of about 2 years 8 months at about 9 cwt. or even less in commercial herds, the Ayrshire reaches 10 cwt. as a second calver and about 11 cwt. as a mature cow. Studies made of recorded animals of the breed show that the lifetime yield is not adversely affected by calving at a very young age, between 24 and 26 months, so that under good management the breed responds to early calving.

Specially selected and bred for its hardiness and its ability to make good use of its food for milk production purposes, the Ayrshire's milk yield performance is about half-way between the Dairy Shorthorn and the Friesian but the fat content is higher. Their milk is pale in colour and the fat globules are small making the milk suitable for feeding to infants.

Since 1950 the expansion of this breed has slowed down owing possibly to the more recent encouragement given to beef by the Government's price policy and by their subsidy schemes for calves, for the breed is of a more extreme dairy type than the Friesian and in this respect approaches the Channel Islands breeds (Plate XXXIXb). The Ayrshire Cattle Society was founded in 1877.

The British Friesian. Before 1880 when an embargo was placed on all importations of cattle for breeding purposes into this country, there had been constant importations of Dutch cattle into eastern England. In 1909 the British Friesian Society was formed to foster the interests of the breed, and in 1914, 50 specially selected animals were imported from Holland. Later there were further importations from South Africa and Canada. The 1936 and 1950 importations from Holland carry marked dual-purpose qualities in this breed, and in the last 20 years the breed has forged ahead overtaking the Shorthorn.

Friesians are strongly built animals outweighing the Ayrshire and Shorthorn with the mature animal reaching 12–13 cwt., with abundant bone and large barrel, indicative of the capacity to consume an abundance of roughage. The colour of this breed is black and white in sharply defined patches and the legs should be white immediately above the hooves. Occasionally dun- and red-coloured animals occur, but these are not eligible for registration (Plate XLa).

As a breed it is unchallenged on milk yield, but the milk tends to be lower in butterfat accentuated by its poor colour, while the fat globules are small and the cream line in bottles is not well emphasised. Breeders have done much to improve the quality of milk in this breed, and the percentage of butterfat is steadily increasing. Allied with the capacity for high yields, is the development of large udders, though these are not so shapely as those of the Ayrshire and Channel Island breeds.

The expansion of this breed has resulted in a far greater proportion of crosses than for any other breed, pedigree cattle form a smaller proportion of the breed than other dairy herds.

The breed has good powers of adaptability, but is best suited to good conditions of housing and feeding, and responds well to generous treatment. The calves are large, often 90–100 lb. at birth which gives them a marked advantage over the other dairy breeds for sale as veal. The change in the type of Friesian to conform more closely to dual-purpose ideals in recent years has also given the breed much prominence as a producer of rapidly growing steers. The Friesian cow when fat is a much better butcher's beast than any of the other single-purpose dairy breeds.

Another strain of Friesian cattle originating from Canadian importations, known as the British-Canadian-Holstein-Friesian with a separate Herd Book has been established in recent years principally in East Anglia, with characteristics broadly similar to the British Friesian but less dual-purpose in type than the present British Friesian as influenced by the 1950 Dutch importations.

The Guernsey. The islands of Guernsey, Alderney and Sark are the native home of the Guernsey cattle which are kept pure by the fact that since 1763 the importation of live cattle to the islands has been banned. Since 1820 there have been shipments of these cattle to Cornwall and the breed has established itself in the southern half of England and particularly on the Isle of Wight.

They are similar in many of their qualities to the Jerseys, but are slightly larger in size and give greater yields of milk of somewhat lower fat yield than the Jerseys, 4·57 per cent butterfat.

Their increased size is often acceptable to many commercial milk-producers as an indication of a stronger constitution than the Jersey. In colour they are various shades of fawn, usually associated with white markings (Plate XLB). The milk produced is an even deeper colour than the Jersey milk and earns a similar price premium. The Guernsey Cattle Society was founded in 1884.

The Jersey. This breed is again based initially on island bred cattle—the small island of Jersey contains less than 40,000 acres. As for Guernseys, restrictions on importations of cattle to the Island have been in force since 1763. Admission to the herd book entails inspection as well as registered parentage, and no heifer is inspected until she has calved ; this means that any animal in the Island herd book is not only pure bred, but also reaches a certain standard of merit.

The Jersey is one of the smallest of the dairy breeds but is very graceful (Plate XLIA). The colour may be light and dark fawn, brown, silver grey and mulberry.

In proportion to their size they have large barrels, an indication of their ability to consume bulky foods. This breed calves at an earlier age than any of the other breeds (2 years 4 months) and at even a younger age it shows no decline in performance.

They produce the richest of all milks produced by various breeds of cattle, average butterfat percentage is well over 5 per cent. The milk is very deeply coloured and large fat globules give a well-marked cream line in the bottle, and this milk commands a premium of one half-penny per pint over ordinary milk.

The Jersey has good powers of adaptability, and refinement of bone and frame are not necessarily a sign of constitutional weakness. The breed is usually found where conditions and climate do not require the cattle to be subject to exposure to cold weather. It is used for mixing with both Ayrshire and Friesians to improve the cream line and the colour of the milk. The Jersey Cattle Society was founded in 1878.

The Kerry. This is a breed of small black cattle of pure dairy type, native to Ireland and weighing about 8½ cwt. They adapt themselves to their surroundings and are hardy. Commercially they do not play any dominating part in the sphere of farm milk production as they have a limited distribution. The herd book society was formed in 1900 and registered 110 animals in 1954 (Plate XLIb).

LIVESTOCK JUDGING

From the description given of the various breeds of cattle in Great Britain it will be realised that each breed is characterised by certain breed "points" or trade marks typical of the breed. Such characteristics as coat colour, the presence or absence of horns, or the degree of fleshing as between a beef and a dairy animal are all identifiable by inspection and are, in conjunction with the general appearance of the animal, the basis of inspection judging as frequently carried out at Agricultural Shows.

Of recent years, however, increasing attention has been given, not only to inspection points, but to economic merit ; beauty with utility is the modern breeders' aim. Few of the inspection points are closely correlated to utility, so that to establish economic merit in cattle we have to resort to methods of measuring actual performance. To date, in the sphere of cattle production, the greatest progress has been made in measuring milking capacity by recording milk yields. Such recording is now possible for all dairy breeds under National Milk Records in England and Wales, administered by the Milk Marketing Board, or by the Scottish Milk Records Association in Scotland (see p. 629). In beef cattle a similar trend is now appearing, whereby periodic weighings of beef cattle will give an indication of rate of liveweight gain : if these records are followed up to carcase assessment, they will give similar information to the beef producer as to the quality of his end product (beef) as is now available to the dairy farmer in respect of the fat percentage of milk.

TYPE IN CATTLE

Livestock breeders speak of cattle as being of a good or bad type, by which they mean how closely they conform to accepted standards of excellence, based on appearance. Since large numbers of cattle change hands every year without any performance records being available, external appearance or type still has a definite market value.

Type in Beef Cattle. The general conformation of a well-fleshed beef animal is illustrated by the photographs of the representatives of the beef breeds given in this book. A deep level body is set on short legs, with top line and under line running parallel, with very full development of the hindquarters where the most valuable cuts in the beef carcase are to be found. This is illustrated in the above diagram of a side of beef showing the various butcher's cuts, and their relative value. The top quality joints are used for roasting or grilling; the second quality for roasting and stewing; and the third and fourth quality for stewing only. It will be noted how the top quality joints are found along the back and in the hindquarters; our modern breeds of beef cattle show outstanding development of these parts of the body as compared with native or un-improved cattle.

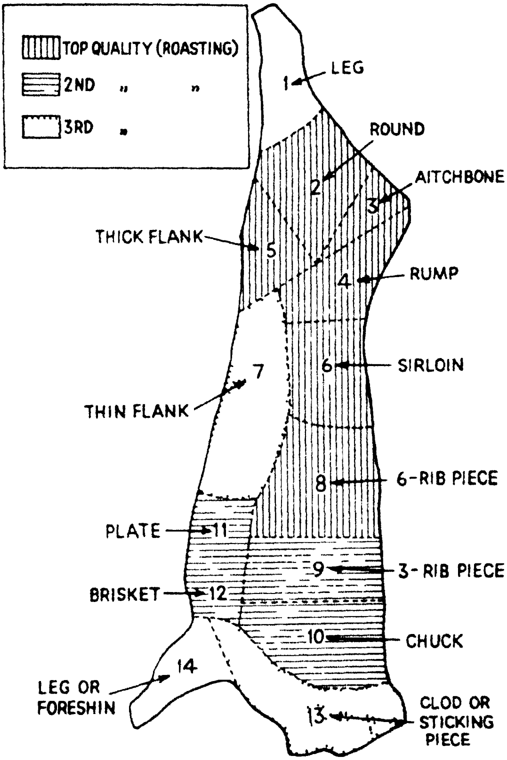


FIG. 114. JOINTS AND THEIR VALUE IN A SIDE OF BEEF (after Wood and Newman 1928)

The beef breeder looks therefore for indications of high carcase quality, as determined by bodily conformation in beef cattle, at all stages of development. Conformation is, however, determined by the level of feeding or plane of nutrition on which cattle are reared, as well as by their heredity or in-born characteristics. Poor nutrition does, for example, retard the development of muscular tissue relatively more so than in the case of bone development, so that beef cattle reared on a relatively low plane of nutrition grow long in the leg, narrow in the hindquarters and with disproportionately large heads. Such cattle tend, when eventually fattened, to produce carcases deficient in muscle (lean meat) and with an unduly high proportion of bone. Modern taste is for lean meat, and the trend in beef production today is towards a sustained high level of nutrition throughout life with no lengthy " store " period, giving a high proportion of lean meat where the growth rate potential of the stock is high (see p. 577). Should, however, cattle of a high potential be subject to a period of underfeeding (or " store " period), this suitability for high-class beef production is impaired because conformation suffers. The buyer of store cattle for fattening consequently needs to be a sound judge of beef type to decide whether any faults evident in conformation are due to the breeding of the cattle or to faulty, or too severe restriction in, feeding.

Type in Dairy Cattle. In contrast to the deep fleshed " blocky " conformation of beef cattle, the dairy breeds exhibit a much more " angular " appearance, particularly in the cows. All high-yielding dairy cows when viewed in silhouette exhibit what has come to be known as the " wedge shape " ; the underline and top line converging to a point beyond the head of the cow ; viewed from behind, a similar wedge is seen running forward from the hip bones to the withers, or shoulder top.

Skeletally the dairy cow tends to be longer and flatter in the bone than the beef cow, but the main differences in external appearance are due to the greater mammary development and thinner covering of flesh in dairy cattle. Physiologically the difference arises from their differing metabolic processes as controlled by the endocrine glands, and it is significant that the anterior pituitary gland, which is so important in controlling and initiating milk production, is much more highly developed in a dairy cow than in a beef cow.

The difference in type, then, between dairy and beef cattle largely arises as a result of the use to which the food they eat is devoted. In beef cattle flesh formation has priority, whereas in dairy cattle milk production is the dominant physiological activity. Dairy cattle will fatten when dry, but tend to give inferior carcases to the pure beef cattle, particularly in respect of the most valuable cuts ; for example, the eye muscle in the rib joint is less well developed, the rump and thighs are less deeply fleshed and the proportion of bone is higher.

In assessing present or future milking properties in dairy cattle, the most reliable guide is the extent and development of mammary tissue. A large capacious udder, free of fatty tissue and silky in skin texture, and which milks out well is looked for, with capacious milk veins running forward from the udder along the under side of the abdomen.

Each of these veins disappears into a " milk well " in the region of the 6-8th rib, and the size of the milk well is as good an indication as we have of probable milking capacity.

Recent work in the United States has indicated that by handling the developing udder of heifers at about seven to eight months of age, an experienced operator can judge, with a high degree of success, future milking ability. Apart from secretory capacity, however, the modern dairy cow requires an udder well attached to the body and which does not become unduly pendulous with age ; above all it must have teats of suitable size, well placed for machine milking, and with teat orifices large enough to give a full flow of milk. Quick milking cows are highly desirable with modern milking equipment.

Further characteristics which are important in judging cattle, whether of beef or dairy type, are ability to walk well (sound feet and legs are essential in long-lived breeding stock) and ability to convert bulky foods, such as hay, silage and grass, economically into meat or milk. Since cattle are ruminants, ample digestive capacity needs to be linked to high productivity, so that judges look for well-developed abdominal organs, or " barrel " capacity. Finally, temperament is of some economic importance ; cattle of an equable disposition are easier to handle, and expend less energy, thus reducing maintenance feed requirements.

ASSESSMENT OF MERIT IN CATTLE

It will be realised from the above discussion, that livestock judging by inspection still has its value but is by no means the final measure of an animal's merit whether for meat or milk production. We can summarise the place of livestock judging in assessing merit in our cattle in the following scheme :

1. Judging by Inspection establishes :

(i) Conformity to breed " points "—colour markings, udder shape and attachment, etc.

(ii) General appearance—beef or dairy type, levelness of top line, soundness of feet and legs, etc.

(iii) Temperament and state of health.

2. Productive ability is established by :

(i) Milk recording in dairy cows (see p. 629).

(ii) Recording of growth rate in beef cattle or *Performance Testing.*

3. Fertility is measured by :

(i) The conception rate with bulls, or percentage of conceptions to services; 70 per cent is good; 60 per cent is average; 50 per cent is poor.

(ii) Calving sequence with cows ; the *calving index* or period which elapses between successive calvings is a common index of fertility, though by no means rigid—an index of 365 days is often used as a standard.

4. Breeding merit is assessed by :

(i) Testing the performance of progeny ; this is of the greatest value in judging the merit of bulls, particularly dairy bulls ; many livestock men today hold the view that this is the only logical basis of assessing the merit of bulls. For a further discussion on *Progeny Testing* see Chapter XVI.

No livestock judge is competent to assess cattle in order of merit in respect of categories 2, 3 and 4, unless he has the necessary recorded data available. At livestock shows in the future, it can be confidently predicted that such information will be much more freely available, to give real distinction to the awards of merit made. The breeder of cattle also needs to follow the same path in the selection of his breeding stock.

CALF REARING

The health and future well-being of the calf is laid by good feeding and management from birth to six months of age. Methods of rearing vary, but common to all methods is the need to ensure that the young calf receives an adequate supply of colostrum which has the property of building up resistance to those infectious conditions of the bowels often referred to as " scours ". Colostrum is more easily digested than ordinary milk, is rich in Vitamin A and has laxative properties. If cows are milked before calving, their colostrum should be saved by refrigeration for the calves at birth. Where Johne's disease is known to occur in a herd, or where it is desired to rear a calf from a dam known to be a reactor to the TB test, the colostrum should be pasteurised. Where colostrum is not available a substitute can be used, and a calf should also be given an injection of blood serum as soon as possible after birth, thus transferring the protective antibodies from the blood of the cow to the calf, as normally happens where true colostrum is fed.

Adequate warmth is also important as young calves are easily chilled, and up to three to four weeks of age lack the heat-producing mechanism of the cud-chewing adult ; they should be kept in warm dry quarters for the first month.

Single Suckling. The simplest and easiest method of calf-rearing is the single-suckling system, each cow rearing her own calf. This is most common in beef production, it is the method most expensive in overheads but it is justified where first-class suckled calves are the aim and where the cows can be outwintered and cheaply fed. Calving in such suckler herds is usually timed for March/April so that the calves are old enough to take the flush of milk at the beginning of the grazing season. Later calvings may mean too much milk for the calf and consequent severe scouring unless the cow is kept on a bare pasture for a time.

Multiple Suckling. This method is followed where better food supplies and buildings are available : each cow can be expected to rear seven or eight or more calves by a continuous process of multiple suckling. At her peak of lactation a good nurse cow may suckle four calves for, say, three months, then three more calves, and then two—making nine in all. But few nurse cows achieve this unless they are specially selected for heavy milking ability. A nurse cow is usually a cull from the dairy herd and may have lost a quarter ; or is a slow milker ; but she will usually make less " fuss " of her foster calves.

A nurse cow is controlled in multiple suckling by being tied up under cover and the calves are then brought to her, otherwise she spends her time out-of-doors or in a yard.

Multiple suckling is a system that fits in well on arable farms where rearing begins in the autumn. One batch of calves is reared before Christmas, a second batch by March and a third during the early part of the grazing season. The biggest drawback to this system, where enough calves are not bred on the farm, is to find suitable calves when wanted. This is most difficult in the spring ; hence autumn suckling should be considered where calves have to be purchased. In any case the cost of, and the mortality rate in, such calves is usually less than in spring-born calves.

To introduce a calf to its foster mother requires patience, and the following technique is recommended. First ensure the cow is tied up and unable to hurt the calf by kicking. Then insert a finger in the calf's mouth and guide the calf into the normal suckling position. Entice its head towards the teat by leading it with the finger being suckled until the cow's teat can be substituted for that finger. Do not push the calf's hindquarters or its head in the hope that it will find a teat to suckle. It may do so, but many nurse cows with pendulous udders require a more subtle technique.

Calves that have been bought in should not be allowed to gorge themselves when freshly introduced to their foster mother, even if it means milking out the cow by hand for the first couple of meals. The new calves should suckle first ; the older calves finish off the cow and wean themselves in the process.

Pail Feeding. The third, and probably in terms of numbers reared the most important, method of calf rearing is by pail feeding on limited quantities of whole milk supplemented by proprietary foods known as *milk equivalents* or *milk substitutes.*

This method requires more specialised accommodation in the way of calf pens and is more exacting in labour demands, but it does enable a considerable saving in food costs to be made. The level of nutrition is lower than in the previous methods and is more suited to rearing dairy type calves. It is important to see that feeding is regular and that feeding buckets are kept scrupulously clean and sterilised frequently, and that foods are mixed correctly.

The calves must be taught to drink from a bucket by inserting one finger into the calf's mouth after the finger has been dipped into a shallow bowl of milk ; as it sucks, the calf's head should be lowered into the milk and the finger removed. A calf suckles more readily at knee height. Whilst the calf is being fed on whole milk, the dilution of milk with 25 per cent water will reduce the risk of digestive scour, as will the avoidance of giving too much milk at once.

This system of calf rearing is now practised in two forms :

(*a*) The feeding of milk substitute or milk equivalent feeds to an age of 3–4 months ; this method is losing favour on account of the labour involved.

(*b*) Early weaning at about five weeks of age. In this system, whole milk is fed for four weeks at about eight per cent of the calf's birthweight to induce the early consumption of concentrates and hay.

TABLE 8

CALF REARING GUIDE

Methods of Rearing

Feeding.	Suckling.		Pail Feeding.	
	Single.	Multiple.	Late Weaning System.	Early Weaning System.
At one week	Suckling dam	Suckling nurse cow	Colostrum for 4 days then whole milk at 10 per cent of birth weight + 25 per cent added water (× 2 feeds). Gradual change to milk substitute—1 lb. replacing 1 gallon whole milk.	Colostrum 8 per cent of birth weight then on milk equivalent made up by adding 1 lb. milk equivalent to 1 gall of water (× 2 feeds). Concentrates and hay offered *ad lib.*
4 to 5 weeks	Suckling dam	Suckling. Hay and concentrates offered as eaten	Milk substitute 1¼–1½ lb. made up with 1¼–1½ gal. water. Hay and concentrates offered as eaten	Milk equivalent 1 lb. in 1 gallon of water. Reduced over 5th week to nil. Early weaning concentrates and hay to appetite
3 months	Suckling dam. Concentrates offered in creep and/or grazing	Suckling. 3 lb. hay; 3 lb. concentrates	Milk substitute reduced from now onwards. 3 lb. hay; 2 lb. concentrates	Now consuming "Early Weaning" concentrates—6 lb. Hay 3 lb.
4 months	Suckling dam. Concentrates offered in creep and/or grazing	Suckling ceases. 3 lb. hay; 4 lb. concentrates	Weaned off milk foods. 4 lb. hay; 3 lb. concentrates	Now consuming 6 lb. calf rearing concentrates; 4 lb. hay
6 months	Suckling ceases. 4–6 lbs. concentrates. Hay as eaten or grazing	6 lb. hay; 5 lb. concentrates or grazing.	6 lb. hay; 3 lb. concentrates or grazing.	6 lb. calf rearing concentrates; 6 lb. hay or grazing
Liveweight gain per day from birth	1¾–2¼ lb.	1¼–1½ lb.	1–1¼ lb.	1–1¼ lb. (Heifers) 1½–1¾ lb. (Steers)
Approximate milk consumption	250–300 gal.	90–100 gal.	10–15 gal. + 1 cwt. milk substitute + 5 cwt. concentrates	Nil + 35 lb. milk equivalent and 6–7 cwt. concentrates
System suited to rearing of	Early beef (beeflings) and stud bulls		Dairy heifers and beef stores for later fattening	

Weaning occurs in the fifth week. The concentrates offered must be very palatable and of high starch equivalent, and the hay of top quality. A typical concentrate mixture would be: flaked maize 50 per cent, crushed oats (or barley) 20 per cent, white fish meal 10 per cent, linseed cake meal 10 per cent, dried skimmed milk 10 per cent, with added synthetic vitamins A and D. "Early weaning" calf foods are available in cube form which increases palatability. Early weaning of calves stimulates development of the rumen and enables young calves to utilise dry food to replace milk with satisfactory live-weight gains, provided the nutrient intake is maintained by high quality palatable feeds.

A summary of the various systems of calf rearing is given on the opposite page.

Rearing Calves at Grass. To reduce calf rearing costs, the New Zealand practice of rearing calves at grass has been developed in this country within recent years. With spring-born calves at grass during the summer, hay and concentrate consumption can be considerably reduced, provided clean grazing at the 4 in. to 6 in. growth stage is available.

Features of the system are: 1. The calves are early weaned. 2. Rotational grazing is practised with groups of, say, 12 calves in ¼ acre paddocks—0·3–0·4 acres per calf being required up to 6 months of age. 3. Shelter in the form of straw bales or a portable shed is necessary early in the season.

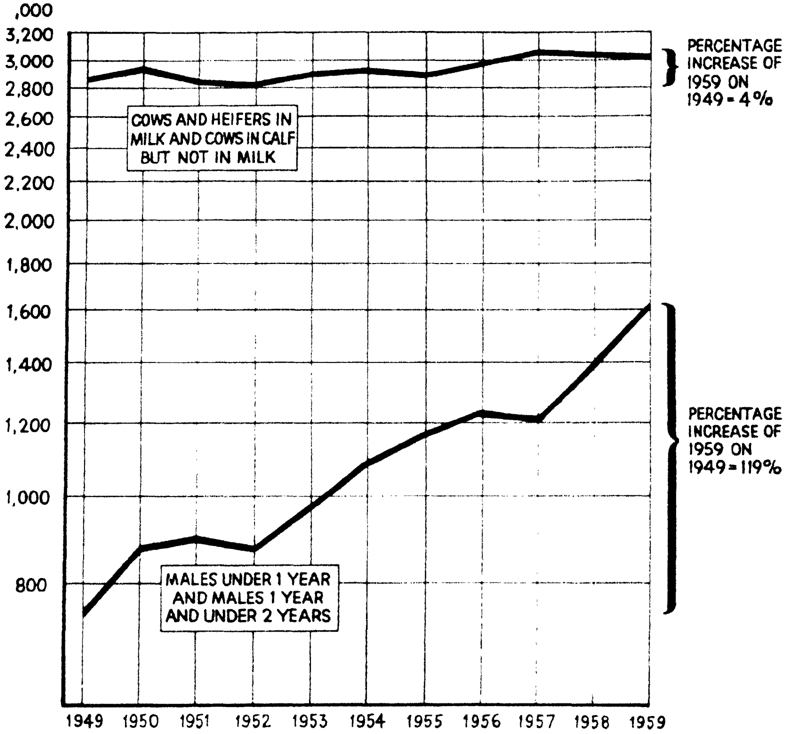
When calves are reared on grass and exposed to a gradually increasing burden of worm infection (gastro-enteritis and husk) they may build up an immunity at a very early age.

Management of Weaned Calves. At weaning time, there is always a slight check to growth rate which is minimised by good stockmanship. Calves, particularly suckled calves, should be encouraged (e.g. by creep feeding) to consume hay and concentrates whilst still suckling. A suitable concentrate mixture for creep feeding and for pail fed calves over four months old is as follows: cereals (oats and/or barley) 55 per cent; flaked maize 20 per cent; linseed cake or meal 20 per cent; and white fish meal 5 per cent. Suckled calves are best yarded when weaning occurs until they have forgotten their dependence on the suckler cows.

BEEF PRODUCTION

The current consumption of beef in the United Kingdom is over one million tons a year or 49 lb. *per capita*, of which some 2/3 is home produced; prime beef, as distinct from cow beef and bull beef, accounts for some 60 per cent of home production, or 40 per cent of the total beef consumed. It is with this production of prime beef with which we are now concerned. Consumer demand in recent years has been for leaner and smaller joints, and this has conditioned the type of cattle used for beef production, the age and live-weight at which slaughtered, and the level of feeding or of nutrition during life.

Type of Cattle. Apart from the pure beef cattle, some 80 per cent of our prime beef comes from cattle bred from dairy cows by crossing with beef bulls. This beef-from-the-dairy-herd trend has made rapid strides in recent years. More than 600,000 dairy cows are now mated to beef bulls, principally Hereford and Aberdeen Angus, by A.I. every year. Both of these breeds, in common with the Galloway, " colour mark " their calves, the black coat colour or the white face of the Hereford being dominant characters, so that progeny from these breeds are easily identified. Beef bulls confer the characters of earlier maturity and deeper fleshing to calves bred from dairy cows ; but the pure Friesian steer in particular is now in increasing favour for beef production because it possesses a high rate of live-weight gain. The use of Charollais bulls, a French breed of cattle noted for deep fleshing and rapid growth, is now under consideration particularly for crossing with the lighter fleshed pure dairy breeds—Ayrshire, Jersey and Guernsey.



Graph illustrating the increasing importance of rearing for beef in the last decade. Figures are for June each year. Source : Ministry of Agriculture, England and Wales.

Level of Feeding. It is now generally accepted that in rearing beef animals a high level of nutrition is required in the first six months of life to produce early development of muscle (lean meat) and bone. If subsequent feeding is continued at a high level, thus telescoping the development of the animal into as short a time as possible, this

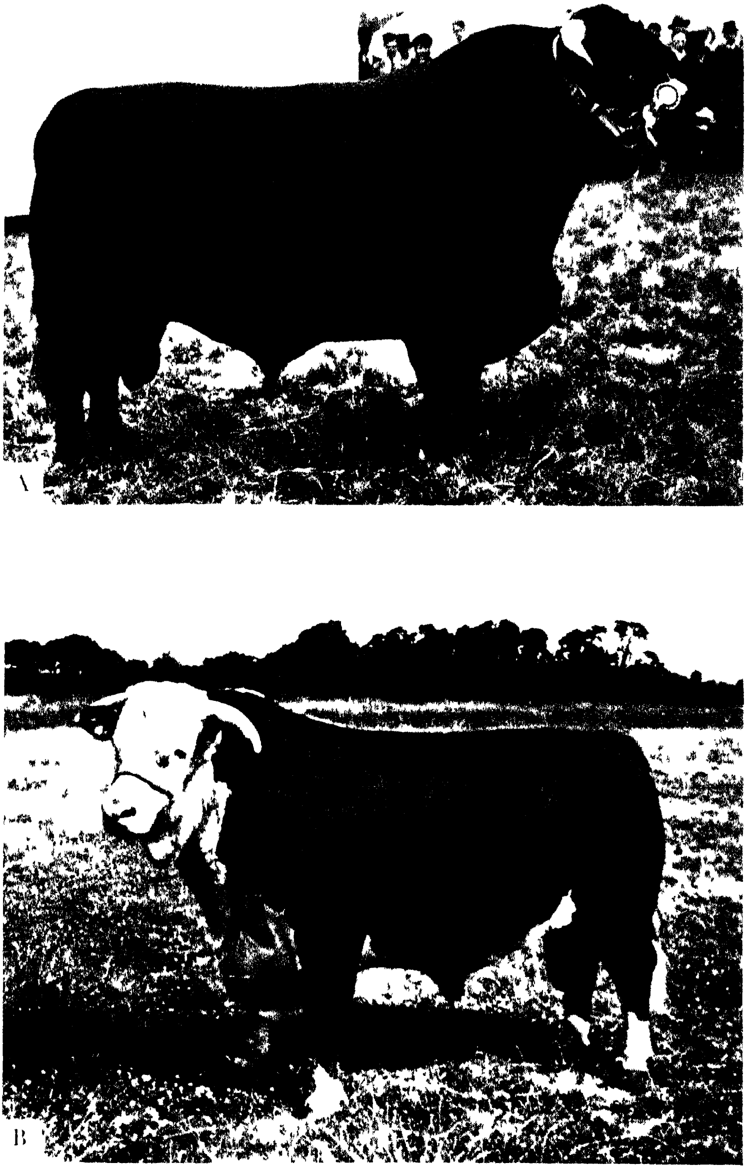


PLATE XXXV

A. Beef Shorthorn Bull

B. Hereford Bull

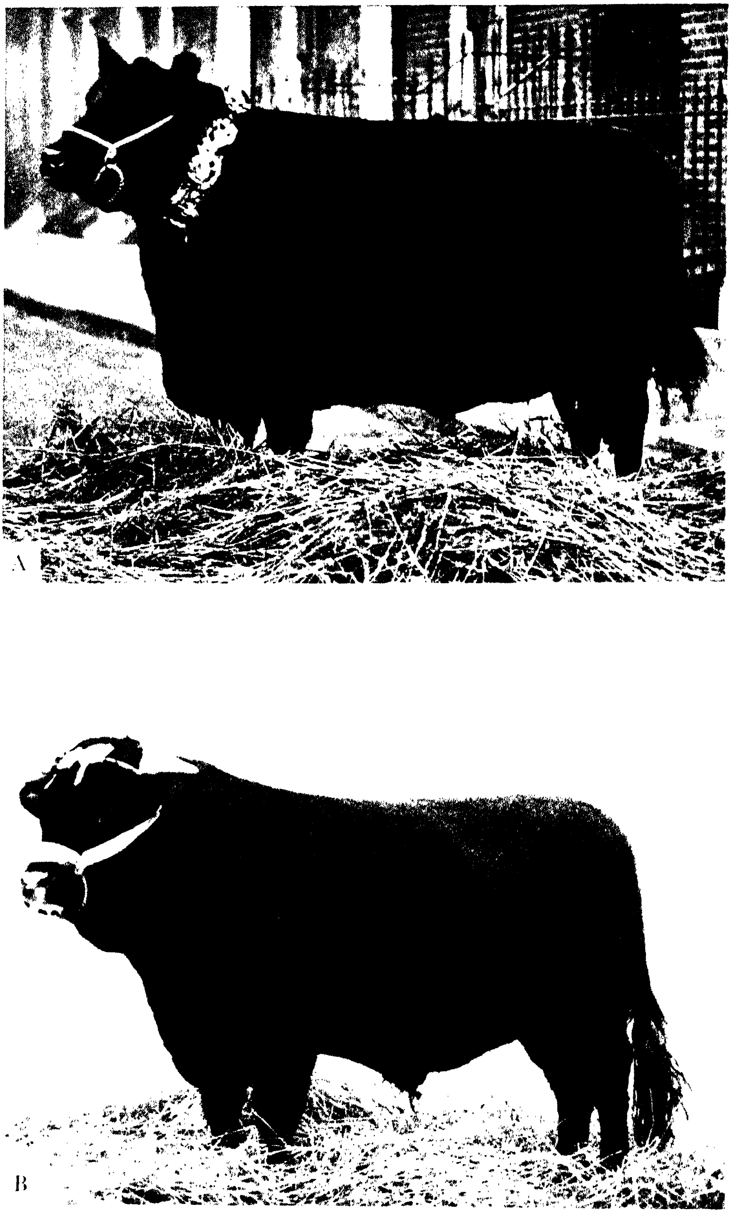


PLATE XXXVI

A. Aberdeen Angus Heifer

B. Devon Bull

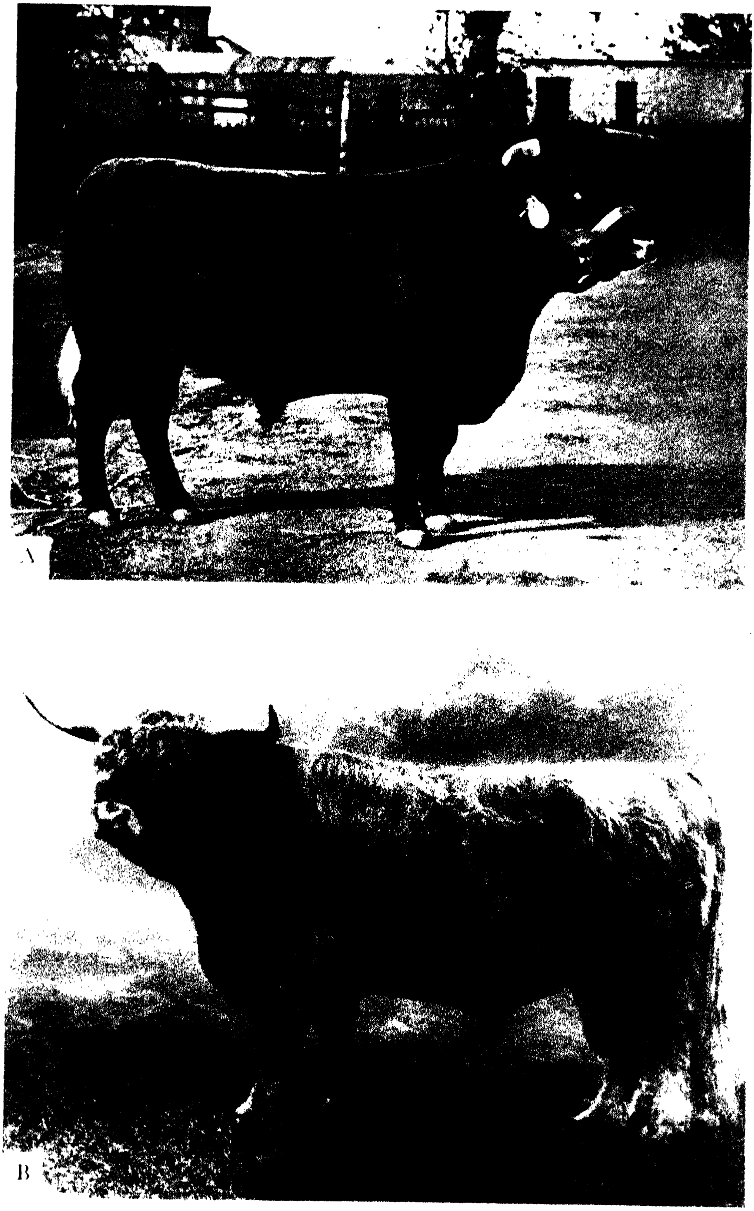


PLATE XXXVII

A. Sussex Bull

B. West Highland Bull

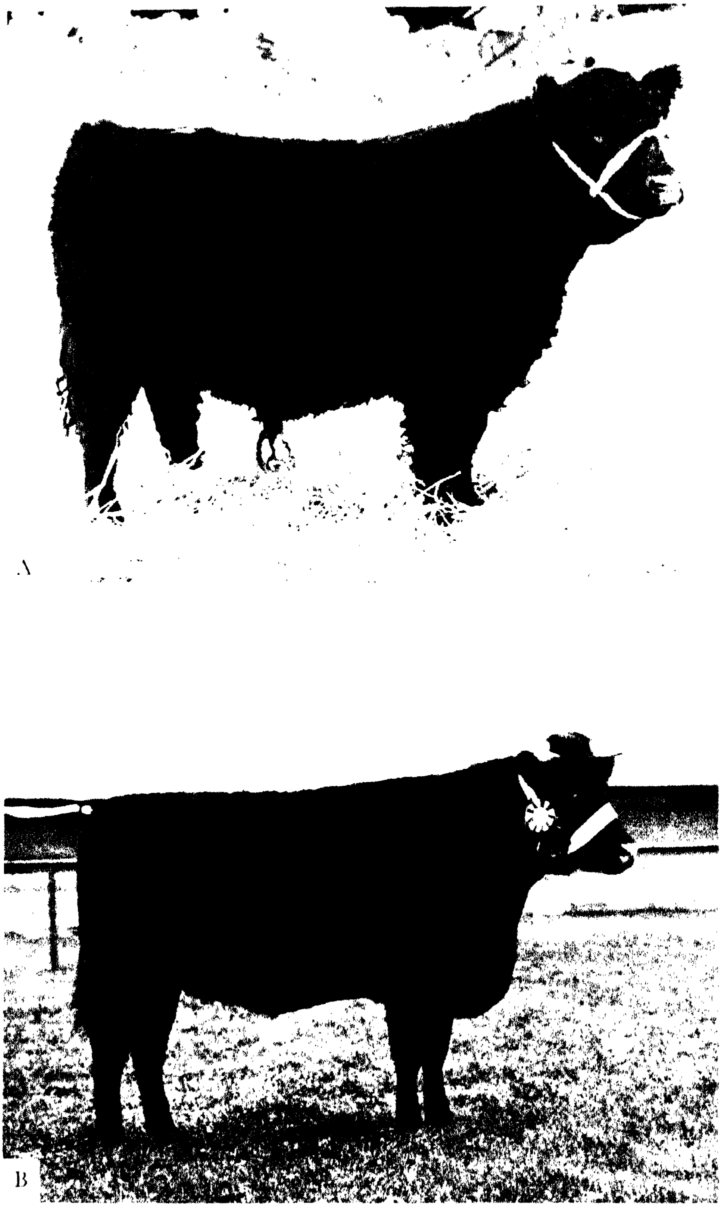


PLATE XXXVIII

A. Galloway Bull

B. Lincoln Red Shorthorn Heifer

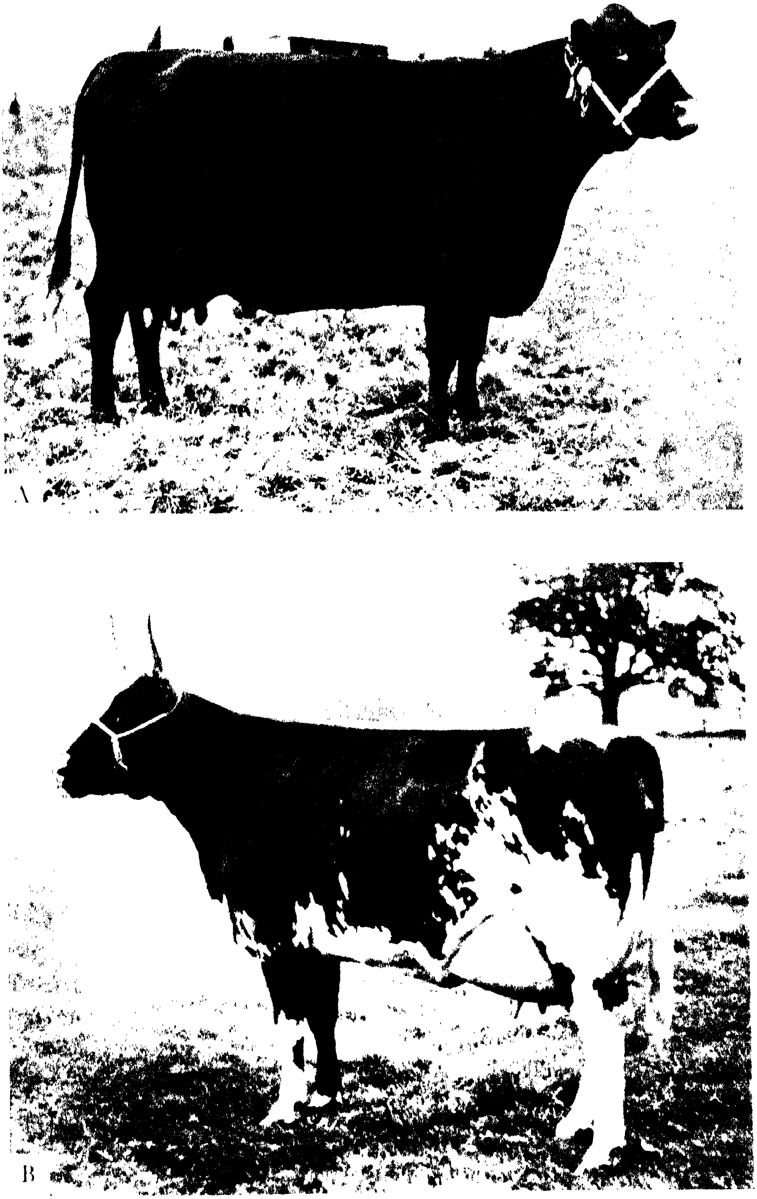


PLATE XXXIX

A. Red Poll Cow

B. Ayrshire Cow

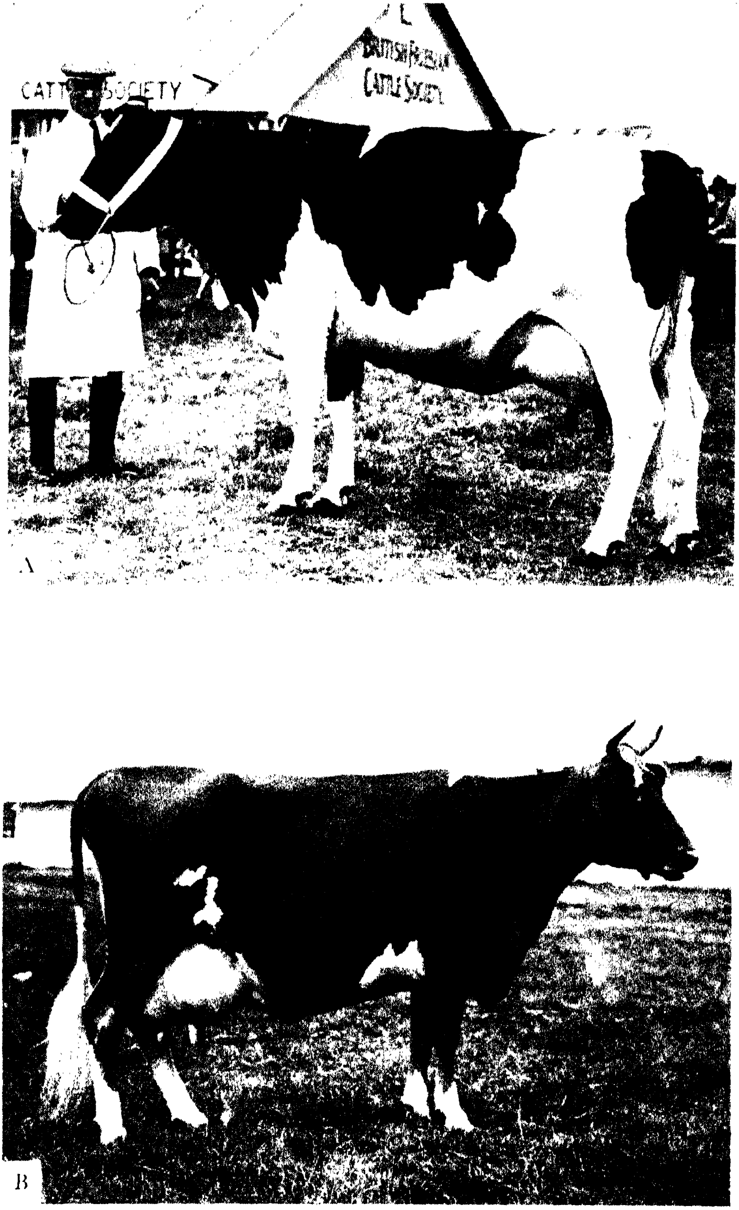


PLATE XL

A. British Friesian Cow

B. Guernsey Cow

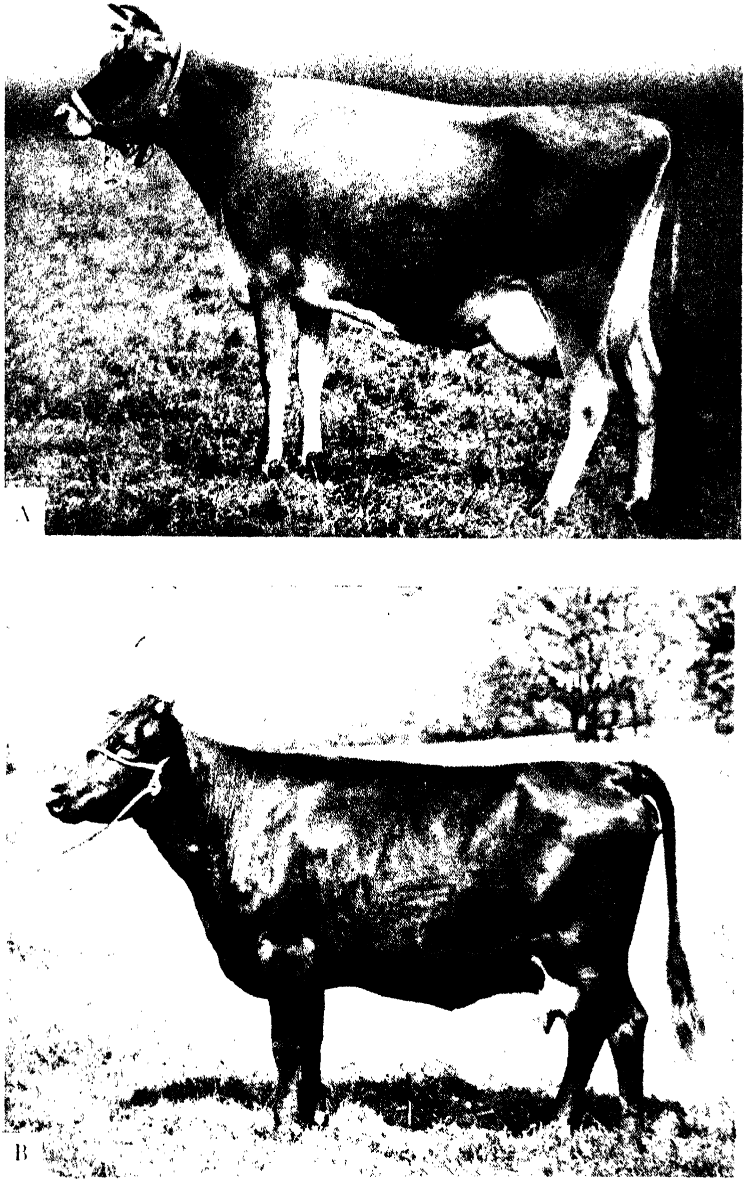


PLATE XLI

A. Jersey Cow

B. Kerry Cow

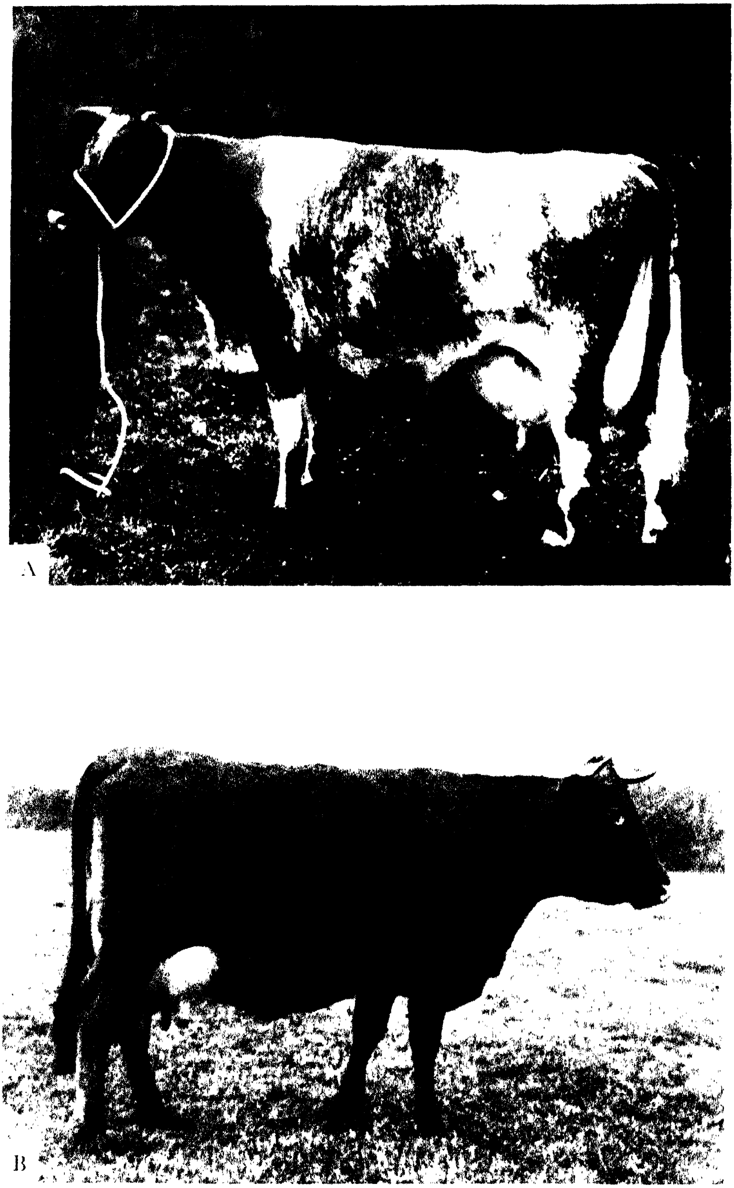


PLATE XLII

A. Dairy Shorthorn Cow

B. South Devon Cow

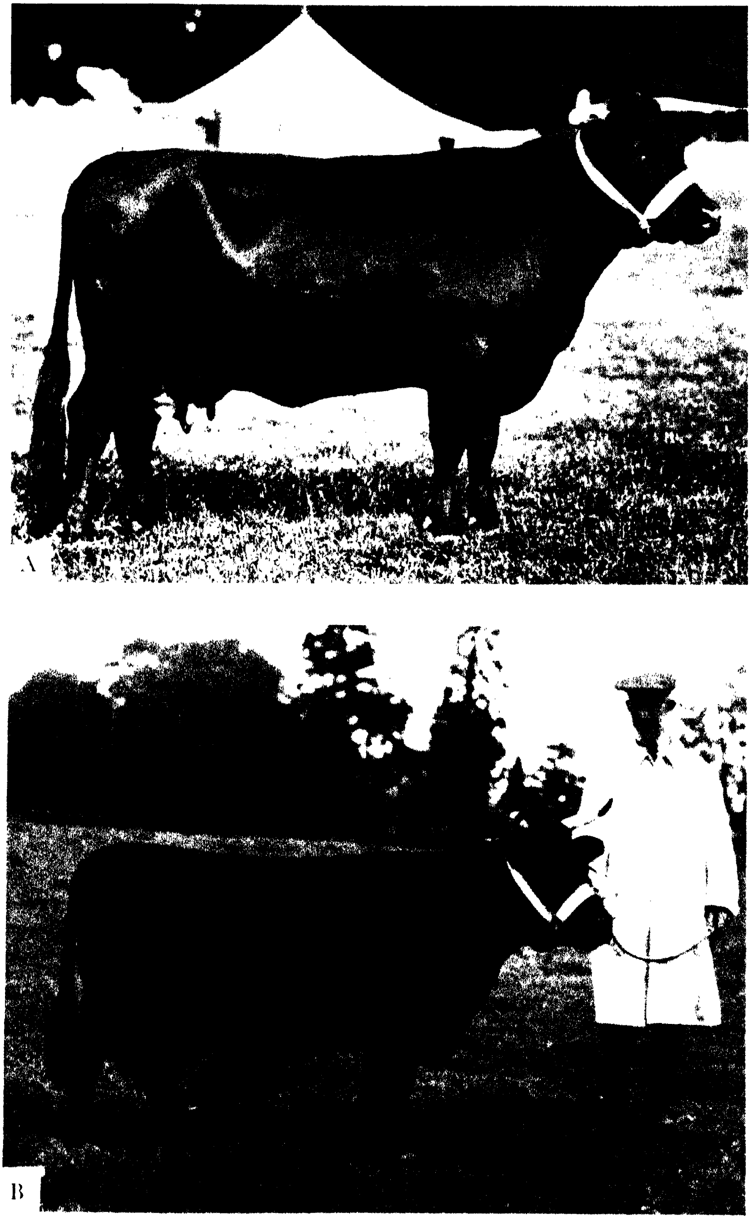


PLATE XLIII

A. Welsh Black Cow

B. Dexter Cow

gives an animal fit for slaughter at 7½–8½ cwt. live-weight at 15–16 months of age. This is the traditional *baby beef*, an expensive type of production because concentrated foods and good quality roughage must be fed at a high level throughout life.

Rearing subsequently on a more moderate plane of nutrition permits full growth of muscle and bone to continue, but final fattening is delayed until the cattle have reached 16–18 months of age ; this produces cattle of 9–11 cwt. live-weight at 20–24 months of age. Because of the opportunities presented to cut feeding costs by utilising a higher proportion of roughage foods, and by shortening the fattening period whether indoors or at grass, this method of rearing, i.e. a high followed by a moderate plane of nutrition as distinct from the high : high planes of nutrition in baby beef production, is now gaining favour.

The third type of beef production involves a low plane of nutrition which involves maximum use of roughage foods, with few or no concentrates, and results in cattle being 2–2½ years or even older before they are put up for fattening. Fattening of such cattle when development of bone and muscle has practically ceased tends to give carcases which are over-fat for present-day demand except for large catering establishments, but represents a means of producing beef (particularly if grass fattened) where concentrate consumption is minimal.

Apart from consumer demand which affects the price received, the level of feeding which the beef producer adopts is governed by the relative cheapness of concentrated foods compared with roughages and grazing. Thus in America today with large grain surpluses on hand, the trend is certainly towards a baby beef type of production, whereas in Great Britain, the high : moderate and the high : low patterns of planes of nutrition are more common. There is the further point that to produce baby beef successfully, cattle of very early maturity need to be used : this characteristic, exemplified so well in the pure beef breeds, is less strongly developed in the beef × dairy cattle which are numerically in the majority in Great Britain.

MANAGEMENT OF BEEF CATTLE

It is certainly advisable to breed naturally polled cattle for beef or to de-horn them as calves thus economising in accommodation when the animals are indoors and reducing the risk of injuries during handling and transport to market.

Cattle in Yards. Beef cattle are usually housed in yards (see p. 73) where adequate trough room to allow all to feed at once is essential except where self feeding on a 24-hour access is employed. From 2 ft. to 2 ft. 6 in. of trough room per head is required. Dry lying is important, for " a dry back and a dry bed are worth an extra feed ". The cattle should be given every opportunity to rest, but housing need not be elaborate, and the margin of profit in beef production is too low for expensive or specialised accommodation. The stockman can contribute towards making the best use of the foods fed by ensuring clean feeding troughs, by even grading of the cattle in size to reduce bullying, and by quiet handling.

Cattle at Grass. The management of beef cattle at grass involves the gradual introduction of the cattle to full grazing in the early part of the grazing season, and this is achieved by an early turn-out and letting the grass " grow to the cattle ". Grazing is supplemented with a continuance of winter feeding, chiefly as hay or straw. If possible, shelter should be available in an open shed or a field with natural shelter (e.g. hedges) should be chosen. By such means the loss in live-weight, particularly with cattle that have been wintered indoors, is reduced to a minimum and the risk of bloat (see p. 711) largely eliminated.

Pastures are usually set-stocked with beef cattle, controlled grazing with electric fences being much less justifiable on economic grounds than with dairy cattle. Common stocking rates are 1 beast of 9–11 cwt. per acre, or two yearlings of 5–6 cwt.

The choice of pasture varies. For fattening purposes, pastures must produce a dense growth of grass over as long a grazing season as possible. This depends on rainfall and the natural level of the water table, so that most of the best fattening pastures are in low-lying areas such as the Norfolk marshes, the Welland valley and the river basins of the Trent, the Thames and the Severn. Less productive pastures are favoured for young cattle not being fattened that season, and these commonly carry sheep as companion stock to the cattle : this makes for better grazing by closer control of grass growth.

General Precautions. Each spring, usually before cattle are finally turned out to grass, they should be dressed against the Warble Fly with a derris preparation (see p. 445) if they were not dressed in the previous autumn with a systemic phosphorus insecticide brushed over the shoulders and down the back. Otherwise except for daily observation to ensure that progress and general health are satisfactory, beef cattle should be disturbed as little as possible.

Labour requirements during the grazing season are extremely low. To assist in drafting out cattle, or for handling individual animals as in cases of lameness requiring veterinary attention, a stoutly built pen and cattle crush sited so as to be of easy access from as many grazing fields as possible is a very great asset. Shade is also appreciated by cattle in the hottest days of summer. A reliable water supply is essential. Access to lumps of rock salt is advised and the drinking trough is a convenient site for such purposes.

FEEDING SYSTEMS IN BEEF PRODUCTION

Against the general background of the management of beef cattle described above, examples are now given of the types of rations commonly fed in the production of beef. It must be emphasised how important economy of feeding is in its influence on profitability ; wherever possible, feeds grown on the farm either as hay, silage, cereals or arable crop by-products such as sugar beet tops, straw and pea haulm silage should be used as widely as possible, rather than the relatively more expensive purchased cereals or high protein cakes. The margin between profit and loss in beef production is so small that wasteful feeding of any kind must be avoided.

TABLE 9

FEEDING FOR DIFFERENT TYPES OF BEEF

	Baby Beef.		Beeflings.			Mature Beef.			
Age (in months)	6	12	6	12	18	6	12	18	30
Plane of Nutrition	H	H	H	M	H	H	L	L	H
Liveweight Gain /day (in lb.)	2	2½	2	1½	2	2	1	1	2
Liveweight (cwt.)	4	9	4	6½	9	4	5½	7	11
Typical Rations in lb./day									
Hay (good)	6	10	6		10	6			12
,, (medium)				6			6	8	
Straw (good)				6			6	8	8
Silage				28	42		28	42	42
or									
Roots				35	56		35	56	56
Concentrates (Cereals)	3	6	3	3	5	3			5
,, (High Protein Cake)	2	2	2	1	1	2			1
				or Grazing			or Grazing		

This table shows the different demands made on feed supplies by the three systems of beef production previously described. Early maturing beef cattle reared on a continuously high plane of nutrition consume, relatively, a lower proportion of roughage (e.g. hay) or succulent foods (e.g. roots and silage) and preponderantly more concentrates. Higher costs of production per cwt. of live-weight are associated therefore with the more intensive systems of beef production, but such systems have the advantage of greatly increased rate of turnover owing to the early age of slaughter.

It should also be pointed out that though baby beef production is often a single enterprise, beeflings or mature beef cattle may well be a joint enterprise in that rearing is carried out on one farm, whilst the store period and final fattening are completed on farms which buy-in their store cattle. This is the common practice on many arable farms (winter fattening) or grazing farms (summer fattening) where the rearing of cattle is uneconomic compared with alternative enterprises, such as cash cropping.

VEAL PRODUCTION

For veal production, beef × dairy calves are very suitable, as are pure bred calves of the dual purpose breeds, notably the British Friesian and South Devon. Calves capable of high live-weight gain and early fleshing are required, the aim being to finish calves of 240–300 lb. liveweight at 10–12 weeks old. Such high rates of gain (2½ lb. daily from birth) are achieved by the feeding of specially compounded milk equivalent feeds based on a Dutch formula incorporating dried skimmed milk and animal fat, supplemented with vitamins and minerals. After the initial feeding on colostrum for four days the milk equivalent is fed at the following rates, mixed with water at decreasing rates of dilution as shown :

Age of Calf (days).	Milk Equivalent (lb.)	Water (pints).	Feeds per day.
7	½	6	3
14	2	10	2
21	3	14	2
42	4	16	2
70 onwards	5	20	2

No other food is given.

In the early stages up to fourteen days of age, food consumption increases rapidly and a high level of stockmanship is required. At the slightest sign of scouring or loss of appetite the quantity of feed given is reduced until recovery occurs. Such setbacks are minimised by controlled ventilation, and insulated walls and ceiling are necessary to maintain an even temperature of 55-60° F. in the calf house. The calves are housed in individual pens—Dutch practice is to tether the calves in pens 56 in. × 24 in. with a floor of slate slats, 3 in. wide, spaced 1 in. apart, standing well clear of the concrete floor of the house. Straw may be used on the slatted floor to give extra warmth to the calves, but is not essential.

A high standard of general hygiene must be observed. Feeding buckets, for example, must be kept scrupulously clean and the feed properly mixed. To assist in this, an electrically heated domestic hot water boiler (10 gallon capacity) in the mixing-room adjoining the calf house is a great advantage. Plastic buckets are recommended, being fitted easily into brackets to serve each pen, the calf feeding through a yoke. A well-designed calf house with pens on each side facing a central feeding passage greatly eases the labour of feeding which should not occupy more than 5 minutes per calf per day. A veal production unit could embrace up to 100 calves as a one-man enterprise.

Profit in veal production hinges largely on rearing the right sort of calf which should not be initially too expensive (costing less than £10 at 4-7 days old) and by good housing and management ensuring that progress is rapid and continuous. In marketing, veal is not at present related to any guaranteed price and unless a return of at least 3*s*. 3*d*. per lb. deadweight is obtained (which makes veal one of the most expensive meats), profit margins are likely to be low—the feed cost, alone, involving the consumption of around 2 cwt. of milk equivalent, is of the order of £15 per calf.

MARKETING OF BEEF AND VEAL

Sales of beef and veal can be on the deadweight or live-weight basis ; in the former, a cash sale is made through certified abattoirs, in the latter, through certification centres as at livestock markets. In comparing returns from these alternative methods of marketing, the farmer needs to be able to estimate the killing-out percentage of his stock which is expressed as the percentage of carcase weight to liveweight. Offal includes the skin, head, feet, tail, intestines, heart and liver, but the greatest " loss " in weight from live to carcase weight is from the contents of the alimentary tract ; hence when weighed at markets, a deduction is often made to give the true or fasted liveweight.

Killing-out Percentages. Well finished mature cattle, two years and upwards, give killing percentages of from 57 per cent to as high as 64 per cent : younger cattle kill out within the range 56–60 per cent, less well finished cattle 54–56 per cent. Cattle killing out at less than 54 per cent are not eligible for deficiency payments. Veal calves have a killing percentage within the range of 52–56 per cent. A high killing out percentage is of considerable importance to the butcher buying on liveweight, or to the farmer selling on a deadweight basis, and varies from animal to animal dependent on the proportion of offal, degree of finish or fleshing, and conformation.

MILK PRODUCTION

Since the institution of organised marketing by the establishment of the Marketing Boards in 1933, milk production in Great Britain has forged ahead—the present rate of expansion in England and Wales alone is 2 per cent a year, and by 1964 production estimates give a figure of 2,000 million gallons for milk sales off farms in England and Wales ; double the production of twenty years ago. Expansion has been based on increased consumption of liquid milk and an extension of milk manufacture into cheese, butter, condensed milk and cream, in that order of importance. Liquid milk consumption is approximately ½ pint per day per head of the population, and manufacturing milk represents some 30 per cent of present production (1960).

Within the industry itself certain significant trends are in evidence. The average size of herd is increasing from just over 15 cows in 1942 to 20 cows in 1960, and the number of herds of less than 10 cows has been halved in the same period. Larger herds save labour per cow, and developments in the housing and milking of cows have been prompted by the same aim to increase output per man. The loose housing of cows in yards, and parlour milking rather than housing and milking in cowsheds, is increasingly evident, the trend being assisted by capital grants under the Farm Improvement Scheme, 1958.

Yield per cow has risen from an estimated 560 gallons per cow per year in 1938 to 735 gallons today, as a result of better management of cows and grassland (from which the cheapest source of feed for dairy cows is obtained) and also by using cows of higher milking capacity either by change of breed or by better breeding methods.

THE REARING OF DAIRY HERD REPLACEMENTS

The average productive life of dairy cows today is between three and four lactations which requires the rearing of some 750,000 heifers as dairy herd replacements every year. The methods of rearing such heifers has a significant effect on the cost of milk production, and the aim should be to rear as cheaply as possible without prejudice to future milking capacity.

Heifers intended for the dairy herd are reared on a significantly lower plane of nutrition than beef cattle, particularly after the first three months of age (see p. 610). A liveweight gain of ¾ lb. per day for Jerseys, 1 lb. per day for Ayrshires and Guernseys, and up to 1¼ lb. per day for Friesians and Dairy Shorthorns has been shown to give adequate skeletal development without the added cost of high condition or fleshing so desirable with cattle being reared for beef. Such a relatively low plane of nutrition permits the wider use of roughage and succulent feeds with minimal use of concentrates. Provided this restriction of nutrient intake is not too severe, saving in the overhead cost of rearing herd replacements can be achieved also by early calving, but early calving should not be achieved at the expense of body size. In-calf heifers should receive better food as calving approaches—with increasing length of pregnancy, so does the plane of nutrition rise. This is illustrated in the following table which traces the development of a dairy heifer (British Friesian) from weaning to first calving.

Table 10

DEVELOPMENT OF A BRITISH FRIESIAN DAIRY HEIFER

Age (months).	Live Weight (cwt.)	Typical Winter Rations.	Summer Feeding.	Remarks.
6	2½	4 lb. hay *or* 12 lb. silage 2 lb. concentrates	Grazing ⅙ acre per head	Vaccinated for Husk before turning out to grass
12	4½	10 lb. hay *or* 30 lb. silage	Grazing 2/6 acre per head	Vaccinated with S.19 at 8–10 months
18	7½	6 lb hay + 6 lb. straw + 30 lb. roots *or* 45 lb. silage	Grazing 3/6 acre per head	Served
24	9	8 lb. hay + 8 lb. straw + 30 lb. roots *or* 60 lb. silage	Grazing 4/6 acre per head	Start concn. feeding in winter 8 weeks before calving at 1 lb. /day. In summer 4 weeks before calving at 1 lb. per day.
27	10½	10 lb. straw + 10 lb. hay + 35 lb. roots *or* 70 lb. silage	Grazing 1 acre per head	Concentrates fed, increasing by 1 lb. per day per week up to calving. Max. 8 lb. /day (winter). Max. 4 lb. /day (summer).

THE MANAGEMENT OF MILKING COWS

Present methods of feeding, housing and milking of dairy cows are conditioned by the necessity for dairy farmers to reduce production costs. In the last ten years labour costs have doubled, purchased feeds have trebled in price, whereas milk prices have risen but 10 per cent.

To reduce labour costs, herds are being increased in size; bucket machine milking in cowsheds and parlours has now almost completely replaced hand milking; loose housing of cows in yards is gaining in favour over cowshed housing because it facilitates the handling of dung by mechanical means (see p. 73). There is an increase in self-feeding of silage, whereby cows help themselves from a vertical "grazing face" at the silo and so reduce labour in feeding. Feeding costs are being reduced by increasing the proportion of bulky foods such as hay, silage, and green forage crops such as kale grazed in situ by the cows, at the expense of the more costly concentrated foods such as cereal grains and high protein cakes.

Details of housing and the lay-out for milking parlours are to be found elsewhere (see Chapter III) and the principles of good grassland management and the production of arable crops for feeding to dairy cows in Chapters X, XI and XII. We are now concerned to know how best to use such feeds available to the dairy farmer.

FEEDING DAIRY COWS IN WINTER

The scientific background to the food requirements for milk production is given in Chapter XVIII. The translation of feeding standards to fit the circumstances of individual farms is based first of all on an estimate of the basic food requirements of cows for the winter in terms of the foods available on the farm. This will enable the dairy farmer to plan his cropping policy in relation to the size of his dairy herd. These requirements are set out in Table 11.

TABLE 11

WINTER FEED REQUIREMENTS OF DAIRY COWS

(Oct. 1st–March 31st)

Breed of Cow.	Winter Requirements (as Hay).		Daily Requirements.	
	Maintenance (M).	M + 1 Gallon.	M.	M + 1 Gallon.
South Devon	36 cwt.	48 cwt.	24 lb.	32 lb.
British Friesian Dairy Shorthorn Red Poll	33 cwt.	45 cwt.	20 lb.	27 lb.
Guernsey Ayrshire	27 cwt.	39 cwt.	16 lb.	24 lb.
Kerry Jersey	21 cwt.	33 cwt.	12 lb.	20 lb.

It is then necessary to find out the "Hay Equivalent" of the Bulk feeds; this can be expressed as follows:

20 cwt. medium hay equals
- 15 cwt. good hay or dried grass
- 25 cwt. poor hay
- 60 cwt. grass silage
- 60 cwt. arable silage
- 80 cwt. kale or swedes
- 100 cwt. mangels
- 60 cwt. fodder beet or potatoes
- 60 cwt. pressed beet pulp
- 10 cwt. oat or barley straw + 60 cwt. kale or swedes

Thus if a dairy farmer plans to feed, say, his British Friesian dairy herd on kale and self-fed silage thereafter, he will need to grow for each dairy cow the equivalent of 45 cwt. of hay to feed for maintenance and the first gallon, or 33 cwt. for maintenance only, over 6 months of winter feeding. This would be met by growing :

$$\left.\begin{array}{l}\text{60 cwt. kale} = \text{15 cwt. Hay Equivalent}\\ \text{90 cwt. silage} = \text{30 cwt. Hay Equivalent}\end{array}\right\}\begin{array}{l}\text{for}\\ \text{M} + 1\end{array}$$

or

$$\left.\begin{array}{l}\text{44 cwt. kale} = \text{11 cwt. Hay Equivalent}\\ \text{66 cwt. silage} = \text{22 cwt. Hay Equivalent}\end{array}\right\}\begin{array}{l}\text{for}\\ \text{M only}\end{array}$$

By a study of the above table, a dairy farmer is able to relate his stocking rate to food supplies. Young stock (or followers) can be reckoned to have half the feed requirements of mature cows, so that a dairy herd of 40 cows and 30 followers is equivalent to $40 + \frac{30}{2} = 55$ cows.

Choice of Crops. In his choice of crops to grow for a dairy herd, the farmer must be guided by the conditions on his own farm as determined by soil type, rainfall, and the equipment available for conservation. Where grass is the master crop, as on heavy land in high rainfall areas, winter feeding is likely to be largely based on silage, or haymaking where rainfall is lower. On arable farms a wider choice of crops is possible, including cereals and sugar beet.

Some guide to the relative cost of different farm crops per ton of starch equivalent (S.E.), and the yield of S.E. per hour of labour involved in growing the crops, is given in the following table :

TABLE 12

RELATIVE COSTS OF PRODUCTION OF FEED CROPS*

	Cost per Ton of S.E. to nearest £.	Yield per Acre S.E. (cwts.)	Yield of S.E. per hour Labour (lb.)
Grass Grazed	12	(13)	1,275
	10	(15)	1,470
	9	(17)	1,670
Grass Silage	20	17·2	98
Arable Silage	27	14·4	80
Meadow Hay	20	13·4	126
Seeds Hay	19	16·4	128
Dried Grass.	36	20·4	74
Kale (Grazed)	15	24·6	224
,, (Cut)	22	33·2	64
Turnips and Swedes . . .	36	21·4	30
Mangels	35	29·3	32
Oats (½ straw)	23	16·6	106
Mixed Corn	25	16·4	102
Beans	38	13·2	63
Concentrates at £30 /ton . .	46	—	—

* These costs of production are based on results obtained from the Milk Investigation Scheme carried out by the Provincial Agricultural Economists in England and Wales. The costs are taken to the end of the harvest and do not include the cost of feeding. They relate to the average of the 1955 and 1956 harvests.

The relative cheapness of grazed crops is outstanding. It should also be noted how higher yields of S.E. per acre from arable crops are only obtained at the expense of reduced output per labour hour, so that increasing output per acre and increasing output per man are to some extent antagonistic. Another point is that conserved grass, whether as hay or silage, is about twice the cost of grass as grazed, which illustrates the more expensive nature of winter as against summer production in feeding costs.

Using Foods to Best Advantage. The second need in feeding dairy cows is to ensure that the foods available are used to the greatest advantage. In this context, good quality home-grown fodder (hay, silage and so on) has a protein-sparing function in that it reduces the need for protein in the concentrates fed in the production ration (see p. 572). Economy in feeding concentrates is thus achieved as protein cakes are more expensive than starch- or energy-providing foods such as cereals.

The supplementation of silage or kale with cereal foods is now a recognised feeding practice. Highly succulent foods such as kale or wet silage (below 22 per cent dry matter) tend to depress the dry matter intake, and supplementary feeding with cereal foods assists in raising the energy intake of diets largely composed of succulent feeds : this may avoid the risk of milk low in solids-not-fat.

Lastly, recent research on rumination has revealed the important role played by the micro-flora of the rumen in the fermentation of food during digestion. This pre-digestion of food in the rumen is markedly affected by the physical condition of the foods eaten by the dairy cow. The cow needs fibre in her feeds in the " long " state. There is no advantage in grinding hay or dried grass which are better fed long, and cereal grains should be rolled, rather than finely ground to a meal form.

WINTER RATIONS FOR DAIRY COWS

Some examples of suitable winter feeding rations for dairy cows are given on p. 618. Few farmers today aim at more than M + 2 gallons from bulk feeds as this enables economy in feeding to be combined with maximum stocking ; to feed for M + 2 gallons, for example, means that only 3 cows can be kept where 5 could be kept if fed to a maintenance level only on bulk feeds, with concentrates being fed entirely for production purposes. There is also the difficulty of getting cows to eat sufficient bulk feeds to provide for the production of more than 2 gallons of milk owing to limitations of appetite.

This table emphasises that with the lower grade fodders such as straw, or average silage and hay, the " saving " in protein concentrates is limited to the first gallon of milk. For yields in excess of 2 gallons, usually a " balanced " mixture of concentrates is fed and this is discussed later.

Self-Feeding of Silage. This practice saves labour, the cows consuming silage from a vertical feeding face, usually at one end of the silo, with unrestricted access over the whole period of 24 hours. The cows eat to appetite which has been found to be of the order of 8–10 lb. of silage per cwt. liveweight of the cow. Low levels of silage consumption result both from silage being too long, and here laceration

TABLE 13

EXAMPLES OF WINTER RATIONS FOR COWS OF 10-11 CWT.

(British Friesian and Dairy Shorthorn)

	Ration per day.	Maintenance (M) lb.	M + 1 Gal. lb.	M + 2 Gal. lb.	Remarks.
	Mainly Grass Farms				
A.	Hay (average) . .	20			Balanced concentrate mixture after 1st gal.
	,, (good) . . .		20		
	Cereals, e.g. Oats, Barley, Beet Pulp (dried)		4		
B.	Hay (average) . .	14			
	,, (good) . . .		14	14	Balanced concentrate mixture after 2nd gal.
	Kale	28	56	56	
	Cereals			4	
C.	Silage (average) . .	60			Balanced concentrate mixture after 2nd gal.
	,, (good) . .		56	84	
	Cereals		3	4	
	Mainly Arable Farms				
A.	Hay (e.g. Lucerne)	7	7	7	Balanced concentrate mixture after 2nd gal.
	Straw	7	7	7	
	Sugar Beet Tops or Kale	28	42	56	
	Cereals		2	4	
B.	Silage (average) . .	28	28	42	Balanced concentrate mixture after 2nd gal.
	Straw	7	7	7	
	Beet Tops or Kale .	28	42	42	
	Cereals		2	4	
C.	Silage	56	56		Balanced concentrate mixture after 1st gal.
	Straw	7	7		
	Cereals		4		

or chopping during making is an advantage, and where the silage is too wet or unpalatable because of faulty fermentation. To safeguard butterfat production some long fodder, hay or straw is beneficial, particularly if the silage has been made from grass cut early in the 6-8 in. growth stage. Rarely will more than 4 lb. of long fodder

TABLE 14

Supplements for Silage

Quality of Silage.	Cereals Fed.	Adequate for.
High (crude protein in dry matter over 15 per cent) .	6 lb.	M + 3
Medium (crude protein 12-15 per cent)	4 lb.	M + 2
Low-medium (crude protein 10-12 per cent) . .	—	M + 1
Low (crude protein below 10 per cent)	—	M only

be eaten. The level of milk production achieved from self-fed silage is mainly dependent on the quality of the silage. Using crude protein content as a guide to silage quality, cereals can be employed as supplementary foods as shown in Table 14.

Feeding of Concentrates for Higher Levels of Production. Reference has already been made in the previous examples of winter feeding practices to the feeding of balanced mixtures of concentrates for yields in excess of one or 2 gallons per cow. Such mixtures are compounded of cereal-type feeds mixed with high or medium type protein feeds and fed so as to provide, at defined rates of feeding per gallon, sufficient nutrients to meet production needs. (See p. 572 for a discussion on the application of feeding standards to dairy cow feeding.)

It is worth noting that the response in milk yield to increasing levels of concentrate feeding is subject to the Law of Diminishing Returns in that feeding of concentrates will increase milk yields at all levels, but at a diminishing rate as yield rises. This emphasises the need for controlled feeding of concentrates *according to the milk yield of the cow and her stage of lactation.* For example an increase of concentrate feeding to two cows both giving 3 gallons of milk per day will give a greater response with one cow in early lactation, say one month calved, than with the other in late lactation, say seven months after calving. No cow will, however, produce milk beyond her genetical capacity ; adequate feeding enables that capacity to be fully revealed, and high yielding cows are distinguished by their ability to respond to rising levels of feeding without diminishing returns operating as soon as would be the case with low yielding (i.e. poorly bred) cows.

In general it can be safely said that the present feeding standards are adequate for all cows in declining lactation, but in early lactation feeding at a level at least 10 per cent in excess of the standards (or ½ gallon above what is actually being given) is justified, particularly to cows of high yielding potential. It has to be emphasised that concentrates have a most important role today in raising milk yields per cow, provided feeding is done with care and discretion to match concentrate intake with the response in milk yield during lactation, and to build up the condition of the cow before calving—known as " steaming up ", or fitting the cow for calving.

Management of the Individual Cow. Cows should be given a dry period of at least 6–8 weeks between the end of the current lactation and the next calving. This rest period makes possible the repair and build up of udder tissue, full development of the unborn calf and the laying down of body reserves to be drawn upon during the next lactation, provided the level of nutrition is sufficiently high. To ensure this, cows during the winter period are fed concentrates, in addition to good quality fodder, from about six weeks before calving in increasing quantity reaching a level of 8–12 lb. of concentrates per day at calving time. Accurate service records and calving dates must be known. During the grazing season steaming up can be at a reduced level, and with May-June calvings cut out altogether when grass is at its maximum feeding value (see p. 614 for steaming up of heifers).

As calving approaches the cow's appetite declines: concentrate or cake feeding is often then reduced and a bran mash or soaked beet pulp given to ensure that the cow is sufficiently laxative, a condition which assists parturition. Wherever possible, cows and heifers should be calved in a loose box, well littered with straw ; and if there is a smooth floor, it should be sprinkled with sand. Assistance at calving should be available if needed in the case of difficult or abnormal births. After calving, the cow is normally allowed to lick her calf dry and the calf remains with her for at least 24 hours or up to 96 hours, before the cow joins the milking herd. On farms where calf mortality is high due to infectious " scours " in calves it is recommended that the calves remain with the cow for the whole of the first four days of lactation, during which the first milk or colostrum is secreted which is so valuable to the calf for its nutritive and immunising properties against bacterial infection.

Milk Fever, which may affect cows at, or soon after, calving, is a condition marked by failure to rise and a typical twisted posture in the neck. The condition is associated with a low calcium content in the blood stream, and is treated by injection of 250 ml. of calcium borogluconate solution either intravenously or subcutaneously (see p. 709). Complications may occur and the advice of a veterinary surgeon should always be obtained ; meanwhile the affected cow should be propped up on her breast bone with straw bales ; if she is allowed to lie " flat out ", she may die from pressure of her rumen contents on the diaphragm causing suffocation.

Feeding after calving should be related to the cow's recovery of appetite. Good quality hay or silage are safe feeds, and the quantity of cake fed is stepped up slowly over the first fortnight, when if recovery from calving is complete, feeding to yield can begin in earnest. Failure to consume food with relish after calving may be due to retention of the afterbirth, causing uterine inflammation (metritis) which is a subject for veterinary attention. Once feeding and rumination are normal and the udder inflammation, common at calving time, has subsided, the cow enters into her full routine of milking and feeding for her next lactation.

FEEDING FOR MILK

During the first three months of lactation, a cow will normally give half of her total lactation yield, and it is during this period that concentrates are most justifiably employed to encourage and sustain a high level of milk production. Rates of concentrate feeding per gallon during this period can, with justification, be raised from, say, 3½ lb. per gallon to 4 lb. per gallon (i.e. feeding in advance of yield) as long as milk yields continue to rise, thus matching output with greater nutrient input. By the 6th week of lactation, yields tend to reach a maximum or peak limited by the frequency of milking.

Twice daily milking is now usual, but an increase of up to 20 per cent above the peak yield can be obtained by thrice milking, which on most farms today is uneconomic at present milk prices in relation to labour costs.

Once the peak yield is reached, the level of concentrate feeding is reduced to the conventional level, and concentrates should then be fed strictly to yield as production declines. Decline in lactation is normally of the order of 10 per cent per month with cows and 7½ per cent with heifers in their first lactation. If the rate of decline exceeds these levels in a herd, the most likely cause is poor quality fodder, e.g. poor silage or hay leads to shorter lactations and lean cows, unless concentrate feeding is increased or extra supplementary feed given.

Sugar beet pulp, stock feed potatoes or wet brewers' grains are suitable foods which can be purchased to boost the feeding value of low quality fodders. For example, 7 lb. of barley straw can be supplemented with 7 lb. of wet brewers' grains to give the equivalent of 7 lb. of good hay : or 7 lb. of poor hay could be supplemented with 2 lb. of dried beet pulp or 7 lb. of potatoes. Such supplementation of fodders where quality is low is very important in avoiding low solids-not-fat percentage in milk, particularly in the late winter months (see also p. 626). The commonly accepted standards for milk production in terms of starch equivalent and protein equivalent show variation according to the fat percentage of the milk. Recent research by Blaxter has shown the desirability of raising these standards by 10 per cent in early lactation.

TABLE 15

PRODUCTION STANDARDS PER GALLON (10 LB.) OF MILK

Fat Percentage of Milk.	Starch Equivalent. (lb.)		Protein Equivalent. (lb.)	
	Average.	+ 10 per cent (early lactation	Average.	+ 10 per cent (early lactation).
3·7–3·8	2·50	2·75	0·5	0·55
4·2–4·3	2·75	3·0	0·55	0·60
4·7–4·8	3·0	3·3	0·60	0·66
5·2–5·3	3·25	3·5	0·65	0·71

Production Mixtures and Rate of Feeding per Gallon.

Mixture A, using mainly home grown cereals :

		Starch Equivalent.	Protein Equivalent.
Barley (rolled) . . .	2 lb.	1·42	0·14
Oats (rolled)	1 lb.	0·60	0·08
Decorticated ground nut cake .	1 lb.	0·70	0·39
	4 lb. contains	2·72 lb.	0·61 lb.

By reference to the table above it can be seen that if fed at 4 lb. per gallon, this mixture is adequate for milk production of 3·7 per cent butterfat in early lactation, whereas for milk of 4·7 per cent butterfat in early lactation $\frac{4 \times 3{\cdot}3 \text{ lb.}}{2{\cdot}72}$ would be needed = 4·85 lb.

Mixture B, using mainly purchased foods.

		Starch Equivalent.	Protein Equivalent.
Barley (rolled) . . .	1 lb.	0·71	0·07
Dried sugar beet pulp . .	1 lb.	0·60	0·05
Flaked maize	1 lb.	0·84	0·09
Palm kernel cake . . .	1 lb.	0·73	0·17
Soya bean cake . . .	1 lb.	0·64	0·38
	5 lb. contains	3·52 lb.	0·76 lb.

Fed at 5 lb. per gallon this mixture is adequate for milk production of 5·2 per cent butterfat in early lactation, whereas for milk of 3·7 per cent butterfat in early lactation (as above) only $\frac{5 \times 2{\cdot}75 \text{ lb.}}{3{\cdot}52}$ would be needed = 3·9 lb. or approximately 4 lb. per gallon.

By selecting feeds high in starch and/or protein it is possible to reduce the quantity of the mixture to be fed per gallon : and compound dairy cakes are sold with recommended rates of feeding per gallon according to milk quality.

Mineral Mixtures. The need for supplying minerals to dairy cows has already been discussed (see p. 534) ; one of the most convenient means of doing this is to add minerals to concentrate mixtures or compound cakes. Mineral mixtures in covered troughs can also be made available in the field. Deficiency in minerals may cause unthriftiness or infertility as well as lowered production. Trace element difficulties involving lack of cobalt (causing pine) or copper, or iodine, can be corrected by additions to the basic mineral mixture fed, which in most is usually made up of limestone 20 lb., steamed bone flour 20 lb., and common salt 20 lb. added to each ton of concentrates. Mineral mixtures fortified with trace elements are available in proprietary form, and special mixtures containing up to 50 per cent of magnesium oxide (calcined magnesite) are also recommended in circumstances where hypomagnesaemia is likely to occur (see p. 710).

Feeding for High Yields. In feeding for maximum yields, as for instance under test conditions in milking trials or in pedigree herds where cows are fed to capacity to determine their full milking potential in selection for breeding purposes, the limited appetite of the cow for dry matter consumption is overcome by concentrating the total diet. This practice of " bulk control " limits the intake of fodder or succulent feeds and maximises concentrate consumption, so that a highly nutritive low fibre diet is consumed. The maintenance ration is reduced in bulk by substituting such foods as dried beet pulp for hay and succulents, and by cutting out entirely low grade roughage foods such as straw. In order to maintain effective rumination the hay fed should not be less than 1 lb. per cwt. liveweight.

A typical diet then for a Friesian cow, giving say 10 gallons of milk a day, might be : Hay 12 lb. ; Beet pulp 4 lb. ; Concentrates 30 lb. (fed at 3 lb. per gallon).

Such a cow would be fed and milked three times a day and the order of feeding at each meal would be concentrates followed by hay. By such methods herd averages of over 2000 gallons per cow have been achieved with specially selected cows of high milking capacity. With increasing cost of concentrates in relation to milk prices and the additional labour cost and problems of organising three times milking, such methods are losing ground to systems of feeding and management involving lower cost feeding and lower labour input, even at the expense of reducing yields per cow. Such methods have already been described.

However, on small farms with limited land, heavy feeding of concentrates to cows of high milking capacity is still an important means of maximising production and increasing the volume of the farm business to an economic level. Such systems of high concentrate feeding also have greatest application to winter milk production, as in summer with lower milk prices, the substitution of grass by concentrate feeding is uneconomic.

The Summer Feeding of Dairy Cows. To exploit the full potential of grass as the cheapest food for dairy cows during the grazing season it is necessary to have cows calving mainly in the months of February and March so that the curve of production of milk follows the production curve for grassland in conjunction with controlled grazing. Such control involves paddock or strip grazing with rapid eating off of the grass by heavy stocking in 4-5 days, followed by adequate rest periods of 15-25 days between grazings, these being determined by the rate of recovery of the sward. Increasing milk output per acre is correlated with increasing the stocking rate ; but too heavy a rate of stocking may reduce grass consumption to the point where milk yields suffer, so that stocking rate is also governed by the milk yields of the cows.

Grass during the early part of the grazing season is a high protein/low energy feed. Eating to appetite on May grass, a cow consumes sufficient crude protein for maintenance and production of 6-7 gals. of milk, but the energy value is adequate only for maintenance and 3-4 gals. Supplementation of grass is economic only for those cows yielding over 3-4 gals. Restriction of grazing, and feeding of concentrates for yields below 3-4 gals. is possible, but it would not pay to do this because grazed grass costs but little more than half of the cost of cereals on a starch equivalent basis (see p. 616). After the spring flush of grass, the case for supplementing grazing is much stronger, but by using lucerne, or directly reseeded leys sown the same spring, or by grazing catch crops such as rape or Italian ryegrass, the summer grazing gap can be bridged with minimal use of concentrate supplements. Irrigation is another means of maintaining pasture growth.

If grazing is not maintained in periods of drought a low solids-not-fat percentage in the milk may well occur. On the other hand when the cows go out to grass on the early bite, low butterfat percentage is often the problem unless some hay or other roughage such as good oat or barley straw is provided after the morning milking.

As a general guide to summer feeding the following scheme is presented :

Time of year.	Growth stage of grass.	Supplementary feeding.
Early April	4-6 in. young and leafy (grazing controlled 2-4 hrs. daily)	Hay or other roughage 4-8 lb. (for 2-3 wks.). Cereals at 4 lb./gal. over 3 or 4 gal.
Mid-May .	8-10 in. long, still leafy (grazing to appetite)	No roughage needed. Cereals at 4 lb./gal. over 4 or 5 gal.
Mid-July .	Grasses tending to flower (grazing to appetite)	Cereals at 4 lb./gal. over 2 or 3 gal.
Mid-August	Grazing of aftermaths, new seeds or forage crops, or green feed in drought conditions.	Balanced concentrates for yields over 3 gal.
Mid-Sept.	ditto.	Balanced concentrates for yields over 2 gal.

In interpreting this table, allowance must be made for local circumstances influencing grass growth, some of which are under the farmer's control, while others, such as rainfall or temperature (earliness of the season), are not. On the farm, close observation of the cows at pasture will show whether they are getting sufficient to eat, and their bodily condition and milk yields will indicate the quality of the food they do eat. A change in feeding is called for whenever yields start to decline too rapidly or the cows are in danger of getting too lean ; a change to new pasture, preferably young seeds or clean aftermaths, or to grazing a forage crop such as rape may obviate the need for more expensive hand-feeding.

A grazing programme for a dairy herd of, say, 40 cows can be illustrated as follows :

Acreage of crop.	Period of grazing.	Remarks.
5 acres winter rye or Italian or S.22 ryegrass ley	15th–30th April (early bite)	Later ploughed for kale
15 acres perennial rye grass-dominant ley	1st–31st May	Later cut for silage or hay
15 acres timothy /meadow fescue ley	1st June–31st July	10 acres previously cut for silage
5 acres timothy /meadow fescue (reseeded ley)	1st–31st August	Sown direct after kale
15 acres p.r.g. ley (as above)	1st Sept. onwards	Previously cut for silage or hay after grazing off

Appropriate fertiliser dressings must be given in the spring and following each grazing or cutting.

VARIATIONS IN THE COMPOSITION OF MILK

Milk may be considered to be a rather variable mixture of fat, non-fatty solids and water. Average commercial milk approximates to the composition : 87·7 per cent water, 3·6 per cent butterfat, 8·7 per cent solids-not-fat (including 4·6 per cent lactose, 3·3 per cent proteins and 0·8 per cent mineral matter and other substances), but these figures vary widely with individual herds and much more so with individual cows. The present state of legislation requires that genuine milk shall contain not less than 3 per cent butterfat and not less than 8·5 per cent solids-not-fat, but at different seasons many farmers find difficulty in maintaining these standards.

The composition of milk is influenced by many factors, genetic, physiological and nutritional.

Influence of Breed on Milk Composition. Breed has a profound overall influence, since Channel Island herds normally produce milk of much higher levels of fat and non-fatty solids than indicated by the above figures. Many Jersey cows, for example, consistently produce milk containing 5 per cent or more butterfat and more than 9 per cent solids-not-fat (S.N.F.). Generally, breeds that tend to give the higher yields, such as Friesians, produce milk of lower compositional quality and vice-versa but, within the same breed structure, individual cows vary widely in the quality of the milk they produce.

To appreciate the variable quality of milk it is necessary to know how the quality of the milk of an average cow changes throughout her normal lactation of about ten months. The newly-calved animal produces for the first week or two milk of higher quality than the average for the lactation. As her output reaches its peak at about a month or six weeks after she has calved, butterfat levels tend to fall to a minimum and then slowly to rise towards the end of lactation, and very appreciably to rise as she is drying off. S.N.F. levels also begin high, dropping to a minimum at about eight to ten weeks after calving and remaining rather below the average for the greater part of the lactation. They usually rise steadily towards the end of lactation if the cow is in calf again, but may actually fall further if she fails to get in calf. Of the individual components of the S.N.F., the mineral matter tends to remain very steady all through, the lactose content very slowly and consistently falls over the lactation, whereas the protein levels drop very rapidly at first and then slowly begin to rise over the greater part of the lactation.

This typical picture of the behaviour of an individual cow reflects what happens under continuously maintained stall feeding conditions. The majority of cows calve over the autumn and winter periods and may pass from one-third to over one-half of their lactation period under stall conditions ; but mostly they are turned out on grass between March and May and spend the latter part of their lactation entirely on pasture. With the flush of spring grazing, yields are usually stimulated by about 15 per cent, and there is often an appreciable drop in the butterfat content of the milk and a rise in S.N.F. content.

The herd picture must necessarily be the resultant of the contribution made by the individual cows. Generally there is emphasis on autumn and winter calving, and the more nearly the cows are calving together the more closely the herd's milk compositional picture approaches that of the typical individual. Where the breed is one with the normally expected poorest compositional quality, danger periods for the milk to fail to reach the presumptive minimum legal standards are in the late autumn when the peak of post-calving production is being attained ; the late winter and mid summer periods (for S.N.F.) ; with also a temporary drop in butterfat level as spring grazing comes to its flush.

Influence of Age on Milk Composition. The effect of age on average butterfat levels is not very marked but, generally, cows tend to drop by about 0·03–0·05 per cent per lactation.

On the contrary, age has a profound effect on levels of S.N.F. content, the drop being of the order of 0·1 per cent per lactation for the first four or five lactations, slightly less thereafter. This means that an ageing herd is more likely to show poorer levels of S.N.F. in the milk than a younger herd. A heifer with a poor record for S.N.F. in her first lactation is almost certain to get worse in her subsequent lactations.

Solids-not-fat. The broad effects of underfeeding, i.e. supplying insufficient nutrients for maintenance and production, are loss of conditions in the cows, accompanied by a more rapid-than-normal falling away of yield. Underfeeding also has the effect of lowering the levels of S.N.F., and in this respect, although it is usually the protein content of milk that suffers most, deficiency of energy or starch equivalent intake has a more marked effect than shortage of digestible protein.

Where underfeeding has been sufficiently prolonged to cause the level of S.N.F. to drop below 8·5 per cent it is very difficult to effect any appreciable improvement by more liberal feeding with concentrates during the course of the remainder of the lactation. Underfeeding may take many forms other than an actual shortage of bulk of food, and possibly the most general form of underfeeding is sub-standard quality of the bulky foods, in particular hay and silage where maximum reliance is placed on these fodders.

The effect which turning the herd out to spring pasture has on the S.N.F. content of the milk is often dramatic, rises on average of as much as 0·4 per cent being attained within a month before the normal post-flush fall begins to set in again. The more liberally that a herd is fed before grazing commences the smaller is the rise in S.N.F. content of milk with grazing.

The effects of disease, especially of the udder, are likely to be adverse as far as S.N.F. are concerned. Damage by mastitis organisms to the internal tissues of the udder leads to a rise in the chloride content of the milk, and such a rise is offset by a tenfold drop in the lactose content, since milk is secreted at a constant osmotic pressure. Thus a rise of 0·1 per cent in the chloride content (doubling the normal value) is offset by a drop of 1 per cent in the lactose, the net effect being a fall of 0·9 per cent in the S.N.F. content of the milk. The after-effects of mastitis, successfully treated by the usual therapy, are likely to have a permanently lowering influence on the level of S.N.F. in the milk.

Butterfat. Until recently it was not thought possible to alter materially the butterfat content of milk by feeding methods. Some foods, such as palm kernel cake and coconut cake, were alleged to be able to raise the fat content, but experimental evidence was conflicting. Liberal doses of cod liver oil (6–8 oz.) per day could seriously depress fat levels, and the depression continued for some weeks after the cessation of the feeding of the oil.

Nevertheless, it was quite a common experience for farmers to face the possibility of having their milk rejected for low fat content shortly after turning out to spring grazing, and the effect of supplementing the grazing with concentrates often made matters worse. The discovery that long roughage, fed as hay and straw, in adequate amounts could prevent the trouble, or cure it after it had occurred, has had tremendous practical and scientific repercussions. If the same quantity of roughage, ground to a meal, were fed no improvement in the milk fat level resulted.

Spring grass causes a temporary stimulation of yield with often a corresponding fall in fat content of the milk, and the common practice of feeding concentrates (and often succulent foods in the form of mangels) to cows at grass often makes matters worse. It is sometimes difficult to persuade cows to eat roughage when newly turned out to grass, but a good practical measure is to put the roughage just under the electric fence controlling the area being strip-grazed, when it is found that the cows will eat sufficient to sustain adequate levels of butterfat. Too many farmers appear to be afraid to trust young spring grass to produce the amount of milk it is capable of, and the practice of continuing liberal feeding of concentrates is not only wasteful and unnecessary, but may actually jeopardise the sale of the milk by inducing low fat levels.

More recently it has been shown that cooked foods like flaked maize, which are highly digestible and presumably pass rapidly through the rumen, when liberally fed can also have a depressant effect on fat levels unless they are given in conjunction with adequate roughage. Since such foods are frequently included in coarse dairy rations, this provides a further argument against giving them to cattle when high quality grazing is available in the spring.

Underfeeding may have a slightly depressing effect on fat levels, although the principal effect of underfeeding is on yields and S.N.F. levels. Low butterfat levels may also occur in the early autumn when freshly calved cows have access to lush autumn grazing on which they are also fed liberal allowances of kale or beet tops, and are also being fed heavily on concentrates, with no roughage allowances. General experience suggests that about 6 or 7 lb. of long roughage daily are required to sustain butterfat content of the milk at satisfactory levels.

MILKING METHODS AND CLEAN MILK PRODUCTION

Milking premises must be licensed by the Ministry of Agriculture through the County Agricultural Executive Committee, and milking methods must conform to the Milk & Dairies Regulations, 1959. Hand milking, except in very small herds, has now been superseded by either *bucket milking machines* where cows are milked and housed in cowsheds, or by *releaser milking machines* where cows, either yarded or housed in cowsheds, are milked through a milking parlour. The latter system is gaining in favour (see p. 66 for a description of lay-outs for milking parlours).

The Milking Routine for machine milking is basically similar with all types of milking machine and incorporates operations designed to ensure clean milk production as well.

Preparing the Cow. Preparations of the cow for milking involves securing her in her stall—yoked or tied by the neck in a cowshed or confined to her milking stall in the parlour. Quiet handling of the cow is essential because if cows are nervous or frightened the *let down* of milk is inhibited. To encourage this " let down " of milk the udder and teats are washed with warm water (120° F.) to which an antibacterial agent such as quaternary-ammonium compounds or hypochlorites is usually added as a precaution against the spread of mastitis, and such washing reduces the risk of dirt contaminating the milk. Vigorous massage of the teats is recommended as the fore-milk is withdrawn from each teat on to a strip cup to reveal if any clots are present in the milk—a symptom of mastitis infection.

Applying the Teat Cups. Within two minutes of washing the udder and teats the teat cups are then applied, care being taken to see each teat cup is fitted snugly on to each teat. Release of milk ("milk ejection") by the cow then proceeds over a milking time conditioned by the adequacy of milk let down by the cow, by the size of her teat orifices, by her milk yield, and by the degree of vacuum in the milk pipe line.

Degree of Vacuum. Most milking machines operate in the range of 15–18 in. of mercury vacuum, about half atmospheric pressure. Provided preparation of the cow has been satisfactory the majority of cows milk out in 4–6 minutes, dependent on yield. Some slow milking cows with abnormally small teat orifices take longer—up to even 10–12 minutes. Increasing the vacuum will increase milking rate but, at over 18 in. of vacuum, udder injury may result. This is particularly the case if over-milking occurs when, as the milk pipe empties of milk, the teat cups tend to creep up the teats.

Machine Stripping. As soon as milk flow slackens and air bubbles appear in the sight glass or milk-flow indicator, pressure is applied to the teat cup cluster with one hand, and the udder massaged downwards above each teat in turn with the other hand to "machine strip" the cow; such last drawn milk is particularly rich in butterfat. The teat cups are then removed by cutting off the vacuum to the teat cup cluster, which is then hung up ready for transfer to the next cow.

Time Taken in Milking. A summary of the time taken to perform this sequence of operations in a normal milking routine is:

	Seconds	
Washing, udder massage and taking of fore-milk	30	
Attaching teat cups	10	
Cow being milked		4–6 mins.
Machine stripping	40	
Removal of teat cups	10	
Changing cows	20	
Total	110	

The milking routine per cow allowing for contingencies is thus approximately 2 minutes, so that up to 30 cows per hour can be milked by one man provided he has sufficient milking units to avoid idle time. Only by reducing the time devoted to operations in the milking routine, notably washing of the udder or machine stripping, can this through-put be exceeded. The provision of two units per operator with quick milking cows is reasonable, or three units per operator with slower milkers: this should avoid over milking (i.e. keeping the machine on the cow for longer than 4–6 minutes).

In the maintenance of milking machines, vacuum pressure and pulsation rate (usually 50–60 per minute) should be periodically checked: teat cup liners should be changed weekly for de-fatting in 5 per cent caustic soda solution, the life of liners being approximately 24 weeks if used and rested on alternate weeks (i.e. 12 weeks in use).

Cooling. After milking, the milk has with bucket plants to be carried to the dairy whereas in releaser plants, conveyance is via a milk pipe-line direct under vacuum, so that releaser plants result in a 25 per cent saving in labour compared with bucket plants. In the dairy the milk is cooled by a surface cooler or by in-churn immersion coolers operating on mains water or refrigeration, to enhance milk keeping quality.

Milk sold for human consumption is subject to routine keeping quality tests, usually at the buyers' premises : since October, 1960, the methylene blue test has been superseded by the " clot on boiling " test. Where a consignment of milk fails to pass the quick resazurin or platform test on delivery it can be returned to the supplier as unmarketable. Poor keeping quality milk is most likely in hot summer weather or where faulty cleaning and inadequate sterilisation of the milking equipment has occurred.

Cleaning and Sterilising Equipment. Under the Milk & Dairies Regulations, 1959, steam sterilisation is no longer obligatory, and the use of hypochlorites approved by the Ministry of Agriculture is permissible. With parlour milking two developments to save labour in washing up equipment have occurred : first, with in-churn milking the milking clusters, teat cups and milk pipes are stored in caustic soda between milkings (*immersion cleaning*) ; second, a releaser plant can now be fitted up for circulation cleaning *in situ*, the detergent-sterilising solution being pumped through the plant under vacuum. In all cases the milking equipment must first have all milk residues removed by rinsing or by circulating cold water immediately milking has finished.

A further stage in labour saving has also been reached by the installation of storage and refrigeration tanks for the bulk collection of milk. This service is now operated in several regional schemes in England and Scotland, and such tanks, though expensive, fit in admirably with releaser type milking plants. This is the pattern of milk handling for the future.

MILK RECORDING

Official milk records are compiled under National Milk Records organised by the Milk Marketing Board since 1946. Dairy farmers can also record privately but such records are unofficial. Membership of N.M.R. costs on average about 18*s.* per cow per year, ranging from £19 10*s.* for herds under 15 cows to £49 10*s.* for herds over 55 cows. Members weigh the milk from each cow daily or weekly, and recorders visit the herds six times a year, or more if required, to check the accuracy of records, take samples for butterfat testing, and earmark heifer calves retained for breeding. The member keeps a herd register containing a summary of each cow's milk records, calving dates and so on, which is used to compile data in the Bureau of Milk Records run by the M.M.B. to be used by Breed Societies and the A.I. service of the M.M.B. in bull selection and breeding projects, as well as in statistical investigations. The standard lactation under N.M.R. is 305 days from the fourth day after calving, and herd averages are published on this basis. In 1958–59 there were 20,000 members of N.M.R. in England and Wales, one-sixth of all milk producers, with a herd size averaging 26 cows (the average herd size for all producers is 20 cows.) In Scotland, milk recording is run by the Scottish Milk Records Association which offers a solids-not-fat testing service as well.

Milk recording is expensive, but is essential to the pedigree breeder. With all milk producers it assists greatly in feeding cows more accurately particularly with concentrates, in culling of low-producing cows, and in encouraging accurate breeding records in relation both to management of the individual cow and regularity in breeding. There is a margin of some 100 gal. per cow in milk recorded herds over cows in non-recorded herds, which is a reflection of the higher management standards in such herds.

REARING, LICENSING AND MANAGEMENT OF BULLS

The selection of bull calves for rearing as future herd sires is a vital decision in breeding policy. Such calves should be strong and vigorous at birth, and if possible they should be by a progeny tested sire out of a dam of proven merit either in milk production or in beef qualities. Bull calves are reared on a high plane of nutrition and by the time they are ten months old must be licensed by the Ministry of Agriculture.

Licensing. Inspection of the bull and, if approved, official earmarking in the right ear with a crown is performed by the County Livestock Officer. Bulls rejected are tattooed in the left ear with the letter " R ", and must be castrated. Any appeal against rejection must be lodged within fourteen days. In England and Wales three types of licence are issued, and in Scotland four types ; for full details see Appendix IV.

Owing to the wider use of artificial insemination the number of bulls licensed has fallen by nearly 50 per cent in the fifteen years from 1946–60. The amendment of the Bull Licensing regulations to include information on the S.N.F. per cent in the milk of the dams of bulls in addition to butterfat per cent was recommended by the Committee on Milk Composition (The Cook Committee) reporting in 1960.

Once licensed, a bull can be used sparingly until mature when twice a week service can be expected without loss of fertility providing feeding is adequate. Bulls should not be fed so as to become over fat and sluggish in work.

Housing. To maintain sound feet and an even temper, bulls should be housed, preferably in a loose box provided with an outside run, into which a service pen is incorporated with access from outside to admit cows for service.

Bulls should be handled regularly with a firm hand ; workers should not be exposed to avoidable risks by housing bulls in unsuitable buildings. A properly constructed bull pen is a necessity if bulls are to be kept long enough to assess their breeding worth (minimum of 5 years) based on milk yields or liveweight-gain performance in their progeny. During the grazing season bulls can be tethered at pasture, though beef bulls (and some dairy bulls) are often run with the cows, with the disadvantage that service dates may be missed and the risk to personnel is greater, but the conception rate is often higher. With suckler herds of beef cows, heat periods are often short and easily missed if reliance is placed on A.I. and the same is true of maiden heifers being served for the first time.

Feeding. In feeding bulls a fair assessment of their feed requirement is a full maintenance ration based on liveweight plus a " production ration " equivalent to that fed for one gallon of milk (see p. 621). With bulls still growing the production ration is fed at a two gallon level. The following illustrate suitable feeding schemes :

Age of Bull.	Live Weight.	Feeding.
18 months . . . (Immature)	10 cwt.	Hay : 18 lb. in 3 feeds Concs. : 8 lb.
36 months . . . (Mature)	13 cwt.	Hay : 24 lb. in 3 feeds Concs. : 4 lb.

Hay can be replaced by other feeds as desired and the concentrates can be of similar nature to a milk production mixture.

ARTIFICIAL INSEMINATION

An artificial insemination service is provided throughout Great Britain by the three Milk Marketing Boards and today three out of every five dairy cows are bred artificially and one of the three cows is inseminated by a beef bull (see beef from the dairy herd, p 608). Bulls used in the A.I. stud are carefully selected either on pedigree or progeny performance. Young bulls are test mated and their Relative Breeding Value (R.B.V.) obtained by the method of Contemporary Comparison between their progeny and the daughters of other bulls in use in the same herds, which can be achieved on the wide scale of operations in the A.I. service, but would be impracticable to an individual breeder. The ordinary insemination fee is £1, for up to three inseminations per cow, but for specially nominated service with semen from progeny-recorded bulls the fee is doubled. In 1960, over 100 nominated bulls were available in the nominated service covering 16 breeds.

In addition to the A.I. Centres run by the M.M. Boards there are six other privately run centres in England. Notification is usually made between 8 a.m. and 10.0 a.m. by telephone for inseminations the same day, later notification means insemination the following day. Insemination up to twelve hours after the end of the heat period is quite effective. Conception rates are usually between 60-70 per cent.

The A.I. Centres also offer private breeders a service whereby semen collected from the herd sire can be stored in deep freeze and used under licence in the owners' or other herds—such a bank of frozen semen is an insurance against death or injury to a bull. Semen has been stored for up to eight years and still proved fertile. The deep freezing of semen also enables the Boards greatly to extend the influence of outstanding bulls in their own studs.

The potential of A.I. in livestock improvement is tremendous given co-operation between the A.I. Service and the Breed Societies now happily coming to fruition. The Scottish M.M.B. has, for instance, introduced a " payment on results " scheme whereby the breeder of a bull subsequently proven in A.I. above a certain standard receives additional payment above the purchase price of the bull.

Chapter XXI

SHEEP

In relation to its land area Great Britain carries more sheep than any country in the world except New Zealand ; more surprising still is the fact that this high sheep population is maintained in a thickly populated country which is highly industrialised.

In 1938 our sheep population exceeded 25 millions, only 1 million less than in 1898. A decline in numbers during the 1914–18 war was followed by an increase during the decade preceding the war of 1939–45.

But during the Second World War there was a progressive decline amounting to 25 per cent in our sheep population. When hostilities ceased there was a gradual recovery in numbers. This has gained in momentum and, despite a heavy mortality due to very severe weather in 1947, Britain's sheep population is now equal to that of 1939.

Since the middle of the eighteenth century sheep in Britain have been bred primarily for their meat, but in the vast sheep-raising countries of the southern hemisphere wool production has been the main object though, since the development of refrigeration, there has been a marked tendency for the breeding of dual purpose (i.e. wool- and meat-producing) types. One of the reasons why the British sheep industry is so important is that every country which develops improved carcase-yielding types depends upon breeds of British origin for crossbreeding.

Britain's sheep are kept under very varied environmental conditions, on mountains, moorlands, uplands and lowlands. They are even to be found on farms mainly under arable cultivation. But during the past half-century there has taken place a marked shift of sheep from the south and east of Britain towards the north and west ; the greater part of our sheep population is now to be found on land of higher elevation. From this land sheep farming is not easily displaced by other kinds of husbandry.

BREEDS AND CROSSBREDS

No country can rival Britain in the variety of its sheep stock. There exist today more than thirty recognised pure breeds and certain well-defined local types which have not a flock book status. In addition, there are large numbers of crossbreds, which fall into two categories—those produced by systematic crossbreeding, and haphazardly bred " mongrels ".

The recognised breeds can be classified as follows :

Mountain and Moorland Breeds

- Scotch Blackface.
- Swaledale.
- Rough Fell.
- Lonk.
- Derbyshire Gritstone.
- Limestone and Penistone.
- Herdwick.
- Whitefaced Dartmoor.
- Welsh Mountain.
- Exmoor Horn.
- Shetland.

Hill Breeds

Kerry Hill (Wales).
Clun Forest.
Radnor Forest.
North Country Cheviot.
Cheviot.

Short-woolled Breeds

(*a*) Whitefaced and Horned :
  Dorset Horn.
  Wiltshire Horned or Western.
(*b*) Whitefaced and Hornless :
  Ryeland.
  Devon Closewool.
(*c*) The Down Breeds :
  Southdown.
  Shropshire.
  Suffolk.
  Dorset Down.
  Hampshire Down.
  Oxford Down.

Long-woolled Breeds

Leicester.
Border Leicester.
Bluefaced or Hexham Leicester.
Lincoln Longwool.
Wensleydale.
Kent or Romney Marsh.
Devon Longwool.
South Devon.
Improved Dartmoor.

In the following notes on individual breeds frequent reference will be made to size ; in the smaller breeds, mature ewes in good condition reach a live-weight of 70–80 lb. ; in the medium-sized breeds the weight range in ewes is from 100 to 130 lb., and in the large breeds from 130 to 170 lb.

MOUNTAIN AND MOORLAND BREEDS

The Scotch Blackface. Numerically this is one of the most important breeds in the whole of Britain ; it is without rival on the high, heather-clad moors of Scotland and northern England. Flocks are also to be found on Dartmoor and on the Cornish moors. Small in size, the breed is of exceptional hardiness, producing a long, coarse-textured fleece making it well equipped to endure snow and heavy rain. The wool is of value in the carpet-making industry. As in all breeds in this class the mutton is of excellent quality. Both ewes and rams are horned ; the face and leg colour may be black, or black mottled with white (Plate XLIVA).

The Swaledale. This breed of the northern Pennines is gaining in popularity at the expense of Scotch Blackface. It is slightly larger in size, carrying a shorter fleece in front. The face colour is a dark grey with a mealy nose.

The Rough Fell. This breed is found to the south and west of the Swaledale territory and it has a more localised distribution. The face colour is dark with a brownish tinge. Though having a shorter fleece it is claimed to be more hardy than the Swaledale.

The Lonk. Also a breed of rather localised distribution, this sheep is found mainly in the Pennine area of West Yorkshire and East Lancashire. Compared with the above-mentioned Blackfaced types it is larger and carries a finer, denser fleece. There is a considerable amount of white in the face markings.

The Derbyshire Gritstone. Again a breed somewhat local in its distribution—north-west Derbyshire. It is interesting as a transition type from the true Blackface, for it is much larger, hornless, and carries a much finer and softer fleece.

The Limestone and Penistone. Formerly of some localised importance, these are types indigenous to the Southern Pennines, but are not now numerically important.

The Herdwick. Throughout the Lake District this breed is predominant. Its endurance in severe storms and its ability to subsist on very scanty grazing prove that it is one of the hardiest types of sheep to be found in Britain. It must not be classed as a Blackface breed, although it has a coarse type of fleece, for some rams are hornless and, although the face colour in lambs is black, with advancing age the faces turn grey and finally white.

The Welsh Mountain. This is a breed of great numerical importance, for it has no rival on the extensive mountain land of Wales. Unlike the Cheviot, which is polled in both sexes, in this breed the rams are strongly horned. It is very small in body size and has a characteristic narrow-shouldered, long-necked appearance (Plate XLVA). The face and leg colour is a grey white, sometimes with tan markings. The wool is relatively soft and fine, though apt to contain hairy fibres (kemp). In its tolerance of high rainfall conditions and ability to exist on the sparse herbage of mountain land this breed is unrivalled.

The Whitefaced Dartmoor. A flock book has recently been started to revive this old type of Widecombe Dartmoor—one of the hardiest long-wooled breeds developed for moorland grazing.

The Exmoor Horn. This is a breed of considerable local importance on the high land of west Somerset and north-east Devonshire. Ewes and rams bear well-developed horns. The face and leg colour is a dull white and the dense fleece on a compact frame give to this breed a characteristically " chubby " appearance (Plate XLVB).

The Shetland. This interesting survival of the old Celtic fine-woolled type has been virtually driven out of Scotland by the Blackface. The very fine dense wool, removed by hand and not by clipping, is used in the manufacture of the famous Shetland shawls.

THE HILL BREEDS

The North Country Cheviot. This type has been developed from the Border Cheviot, and is very well established in Northern Scotland. It is larger than the Border Cheviot, with larger and less erect ears, and with a longer head than the south country type.

The Cheviot. This rivals the Scotch Blackface in being of very great numerical importance. Throughout Scotland it is found always on the " green " hill land, leaving the " black " or heather land for the Blackfaces. It has invaded Wales and even Exmoor—in fact the Cheviot can be found in many English counties on upland grazings of poorer quality.

It is an impressive breed in appearance with its proud carriage of the head, its bright white face and leg colour, pricked ears, and distinctive ruff of wool behind the ears (Plate XLIVB). The wool quality is much higher than that of the Blackfaced types. The importance of this breed is still further enhanced by the fact that when crossed with the Border Leicester it produces in the " Half-bred " one of the most valuable types of crossbred ewe kept in Britain.

The Kerry Hill (Wales). Originating in the district whose name it bears, this breed is widely met with throughout the Welsh Border area and the Midlands of England. It is a medium-sized breed, polled in both sexes, with a dull white face and leg colour relieved by black markings round the muzzle and above the hoofs (Plate XLVIA). The wool is dense and always markedly coarser on the thighs and breech region. This breed is fairly prolific and is popular on lowland grass farms where a medium-sized breed is desirable. In some pure-bred flocks there is now a tendency to breed too closely towards Down breed standards of conformation ; this will ultimately lead to a falling-off in fertility and milking quality.

The Clun Forest. This breed has become very popular and is now widely distributed throughout the Midlands and also in southern England. It resembles the Kerry in size, in polled character, and in the carrying of coarser wool in the breech region. It differs from the Kerry in having a brownish black face and leg colour (Plate XLVIB). It has gained a good reputation as a type for mixed farms where it can be used to consume crops on arable land during the winter.

The Radnor Forest. This was a local type but is now a recognised breed. It is best described as an intermediate between the Welsh Mountain and the Kerry Hill.

THE SHORT-WOOLLED BREEDS

The Dorset Horn. Differing from all other British breeds this sheep has flesh-coloured lips and nostrils and produces a fine-textured wool which is very white in colour. It possesses another distinct character—it will breed earlier in the year than any other breed, for ewes will take the ram in May to lamb in October. This has made it a noted breed for the production of very early fat lamb. It is found mainly in south and west Dorset, Somerset and the Isle of Wight, usually on mixed and arable farms, for it is well adapted to feeding off arable land crops. It is very docile in grazing habit, resembling in this respect the Down breeds. Both ewes and rams bear well-developed, pale-coloured horns (Plate XLVIIA). While lacking the symmetry of carcase of the Down breeds it excels most of them in fertility rate and milking quality.

The Wiltshire Horned (or Western). Descended from a type once prevalent in Wiltshire, this breed is now found mainly in Northamptonshire and Buckinghamshire. Horned in both sexes, and with virtually no fleece, it is used mainly to provide rams in crossbreeding to produce early fat lambs.

The Ryeland. Originating in south Herefordshire this breed has now a scattered distribution. It is fairly small in size, very docile, and produces wool of good quality and uniformity. The face and leg colour is a dull white (Plate XLVIIB).

The Devon Closewool. Unlike the Ryeland, which is a breed of great antiquity, this is a relatively new breed. It owes its origin to crosses of the Devon Longwool with the Exmoor, in an attempt to produce a type suitable for habitat conditions intermediate between the higher uplands of Exmoor and the rich lowlands of Devon. It is polled in both sexes and bears a dense fleece of fairly long stapled wool.

THE DOWN BREEDS

The Southdown. No other breed in the whole world can challenge the Southdown in carcase quality ; in this breed the fineness of bone and texture of its dense flesh are supreme. In addition, it carries a short dense fleece of high-quality wool. It was the first of the Down breeds to be systematically improved. John Ellman in Sussex, towards the end of the eighteenth century, was the pioneer and his improved Southdowns were soon famed throughout England ; they were used to help in the establishment of the other Down breeds. In features the Southdown is quite distinctive ; it has a strikingly compact body on short legs, a mouse-grey face and leg colour, and its ears are small and rather rounded (Plate XLVIIIA). But it is unavoidable that in breeding for such a standard of excellence in flesh and wool production there is a sacrifice of the milking qualities and of prolificacy.

The Shropshire. This breed is now more widely known and more widely esteemed in the U.S.A. than in England. Though larger than the Southdown it does not approach in size to the other breeds in this class. The face and leg colour is black and it was in the past woolled down the legs and over the poll and cheeks to a greater extent than any other English breed.

The Suffolk. Though originally developed in East Anglia for arable farming conditions, the Suffolk can now claim to be the most widely distributed of all the Down breeds. It is extensively used in crossbreeding, its popularity being in part due to the absence of wool on the face. In sharp contrast to the other breeds in this class there is no wool on the head or on the legs and this clean-headed character has made it popular for mating with ewes of other breeds smaller in size (Plate XLVIIIB). The face and leg colour of the Suffolk is a glossy jet black ; in size it is larger than the Shropshire but inferior to the Oxford.

Both the Shropshire and the Suffolk are naturally more prolific than the rest of the breeds in this group.

The Dorset Down. This breed came into existence many years after the establishment of the Hampshire Down as a recognised breed. It is kept mainly in the counties of Dorset and Somerset. In many ways it is comparable with the Hampshire Down, though slightly smaller in size and having a lighter shade in face and leg colour.

The Hampshire Down. During the latter half of the last century arable-land sheep farming was extensively practised on the chalk uplands of Berkshire, Hampshire, Wiltshire and Dorset. For this system the Hampshire Down was pre-eminently suitable. It was accustomed to graze by day on downland pastures and it was penned at night in hurdle folds on arable crops. No other breed has such tolerance of living under close-folding conditions.

The arable sheep farming system has declined very greatly during the past fifty years and so this breed is numerically less important now. None the less, it is still an important breed since the rams are extensively used in crossbreeding for fat lamb production. It is a large-sized breed, capable of very rapid growth and early maturity if generously fed. It is woolled over the poll, on the cheeks and down the legs ; the face and leg colour is a very dark brown, almost black (Plate XLIXA).

The Oxford Down. This has the largest-sized frame of all the Down breeds, owing its origin to crosses of the Hampshire with the large, long-woolled Cotswold. It was extensively kept on the arable farms of the limestone uplands in Gloucestershire and Oxfordshire. This again is an example of a breed developed for a system of farming now not extensively practised, but the Oxford is fairly widely distributed today because the rams are very popular in crossbreeding to produce store lambs for winter feeding. From its Cotswold ancestors it inherits a high bold head carriage ; it carries less wool on the legs and head than the Hampshire Down, though it has a comparable very dark brown face and leg colour (Plate XLIXB). It must be ranked as one of the hardiest of the Down breeds in its tolerance of wetter soils and higher rainfall conditions.

THE LONG-WOOLLED BREEDS

As a class the long-woolled breeds are now much less numerous owing to the alteration in consumers' tastes which took place rapidly during the early part of the present century. The Longwools produce heavy fleeces of lustrous wool, coarser in fibre than the fleeces of sheep in the short-woolled group. The flesh is coarser in texture and there is some tendency to overfatness. With one or two exceptions, the Longwools have dull white face and leg colours and all are polled in both sexes.

The English Leicester. Systematically improved by Bakewell's careful breeding and selection, this must be regarded as the foundation breed of all other Longwools. Leicester rams were used to grade up other local types from which the rest of the breeds in this class were developed. Though well known abroad it is seldom met with except in north-east England (Plate LA).

The Border Leicester. Like the Cheviot this breed is striking in its high head carriage and absence of wool on the legs and head (Plate LB). It is a breed of first-class importance because the rams are extensively used to cross with Cheviot and Blackface ewes to produce the Half-bred and the Mule or Greyface, both of which are crossbreds of great economic value.

The Bluefaced or Hexham Leicester. In recent years rams of this breed have gained in popularity for crossing with Blackface and Swaledale ewes to produce the Greyface, Mule and Hexham crossbred types.

The Lincoln Longwool. The largest and heaviest fleeced breed in the whole of Britain, though today of greater economic importance overseas. It has contributed towards the formation of the Corriedale in New Zealand (Plate LIA).

The Wensleydale. In contrast to the other breeds in this class the Wensleydale has a bluish-grey face and leg colour with a fleece of silky and finely purled wool. It has not a wide distribution away from the district after which it is named.

The Kent or Romney Marsh. This breed is numerically one of the most important of the long-woolled breeds, and its habitat in the Romney Marsh area is the most densely sheep-stocked area in the whole of Britain. The wool is fairly fine in texture and of very good quality. It is highly esteemed in overseas countries which have specialised in wool production (Plate LIB).

The Devon Longwool. A breed of local importance in south-west England.

The South Devon. Rather similar in type to the Devon Longwool, but larger in size and slightly coarser in fleece. It is found mainly in Cornwall and south Devon.

The Improved Dartmoor. Another Longwool of very localised importance: an interesting type, developed from the original moorland Dartmoor sheep by the use of Devon Longwool rams, and now kept under semi-lowland conditions.

CROSSBREEDING AND CROSSBRED TYPES

Systematic crossbreeding is widely practised by sheep breeders in this country. There also exists, to a regrettable extent, some crossbreeding which is unsystematic, resulting in numerous mongrel types which vary in wool and carcase quality. But when two breeds are crossed to yield a first-cross ewe, which is then mated to a ram of a third breed, this is definitely systematic since it results in the production of standardised commercial types.

Each year the older ewes in all the mountain and moorland flocks are drafted for sale to semi-lowland and lowland farms. Here they will live under more favourable habitat conditions—a higher plane of nutrition and less climatic severity. This environmental change brings about an increase in fertility rate and in potential milk yield. By mating these ewes with rams from breeds larger in body size and earlier in rate of maturity, the crossbred lambs produced have a capacity for rapid growth, for they can use to good effect the heavy milking capacity of their dams. Fundamentally the greatest reason for crossbreeding in sheep is to increase the progeny value of each ewe in the breeding flock.

For mating with mountain and moorland types of ewe both long-woolled and short-woolled types of ram are extensively used.

In many cases from this type of crossing a valuable ewe for further breeding is produced. The following are good examples:

The Halfbred, from Border Leicester on Cheviot.
The Mule or Greyface, from Border Leicester on Blackface.
The Masham, from Wensleydale on Swaledale.
The Welsh Halfbred, from the Border Leicester on the Welsh Mountain ewe.

The wether lambs from these crosses are fattened for mutton, but the ewe lambs are kept for breeding to Down rams such as the Oxford and the Suffolk, yielding second-cross lambs much valued for winter feeding on roots, if not sold earlier off grass.

Another system of crossing, commonly practised to satisfy the considerable consumer preference for smaller and leaner joints, is the use of Down breed rams on the larger Longwoolled ewes. The following are examples of this:

Southdown on Kent or Romney Marsh.
Hampshire Down on South Devon and Devon Longwool.
Suffolk on Lincoln Longwool.

In early fat lamb production crossbreeding has always been a popular practice. Rams of many shortwool breeds—the Ryeland, the Western, the Suffolk, the Hampshire, the Dorset Down, the Southdown—have been widely used, also the Kerry Hill and the Clun. Some areas where the sheep population is high have always a surplus of ewe stock to export to other parts of the country; most of these ewes are used to breed and fatten lambs for early disposal.

In crossbreeding in sheep there are two important considerations which govern the choice of the breed of ram to use: (1) To avoid excessive trouble in lambing, breeds of ram carrying much head wool should not be used on small-type ewes; (2) The time of lamb disposal should also be considered; lambs sired by smaller-type rams are usually more suitable for early slaughter, i.e. before weaning age. Crossbred lambs for sale as stores for winter feeding must be well grown in size of frame. To produce these it is obvious that rams from the larger-sized breeds will give the best results.

GENERAL FLOCK MANAGEMENT

The management of sheep is best dealt with by outlining the management of a breeding flock through the cycle of one complete year. In all breeding flocks the same sequence of operations must be carried out, but according to locality and breed the time of year of the lambing season varies considerably; Dorset Horn flocks are lambed in the autumn, some Down flocks in January, and the latest breeding is found in the mountain breeds which are not lambed until April and early May.

Preparation for Mating. The shepherd's year begins when the breeding flock is made ready for mating. This means, in the first place, the sorting or culling of the flock ewes to ascertain those fit for retention for a further year's breeding and the addition of young ewes to make up the desired flock number.

Culling. Culling is an operation which must be carried out with great thoroughness, for age, fitness for further breeding, and type,

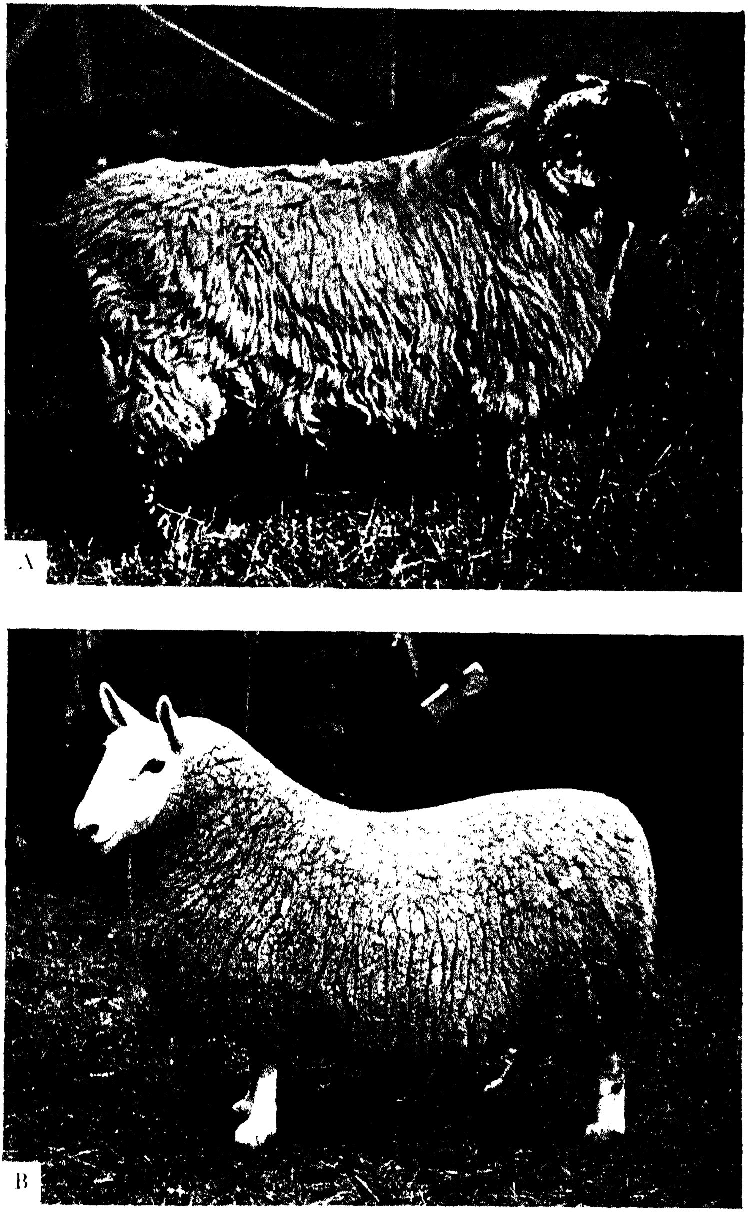


PLATE XLIV

A. Scotch Blackface Shearling Ram

B. Cheviot Ewe

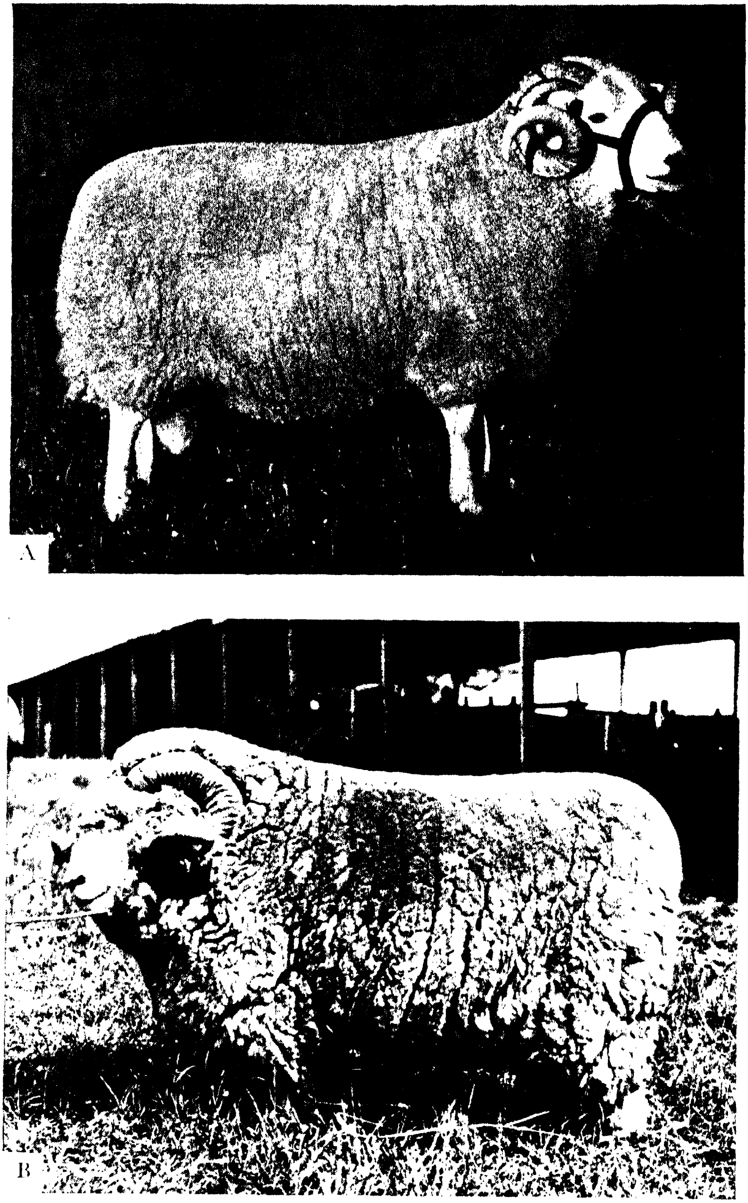


PLATE XLV

A. Welsh Mountain Ram

B. Exmoor Horn Ram

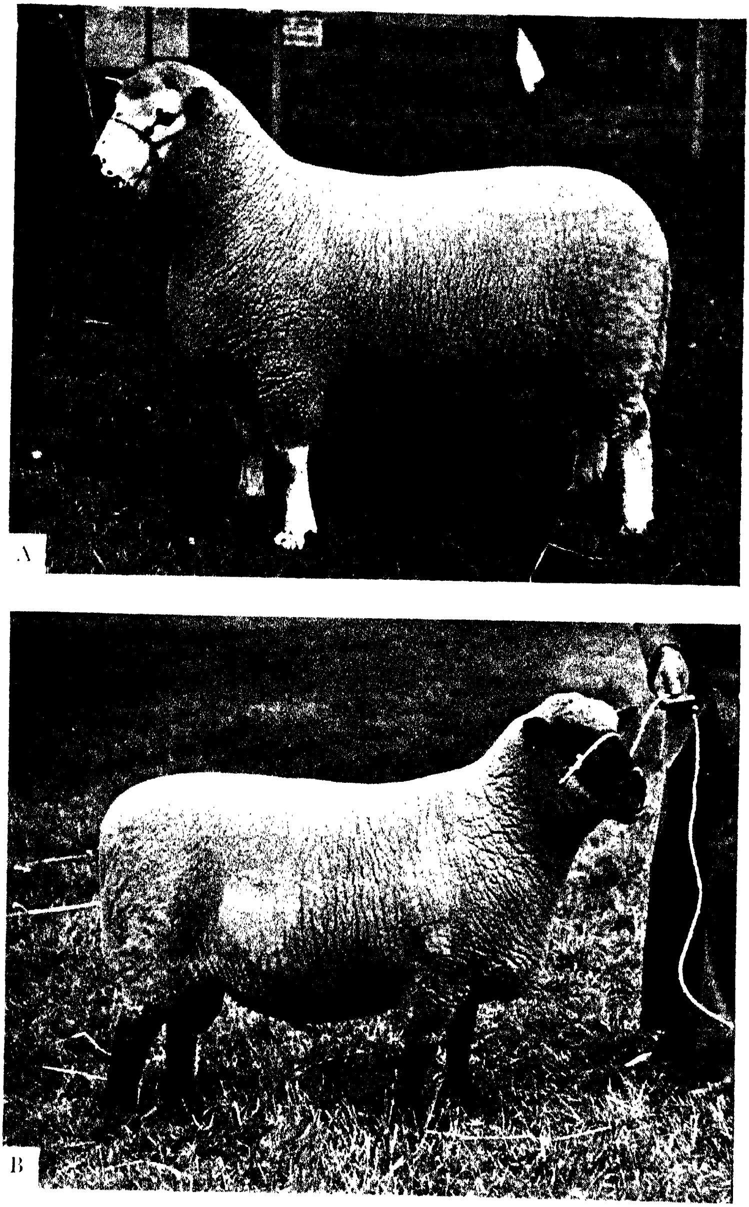


PLATE XLVI

A. Kerry Hill Ram

B. Clun Forest Ram

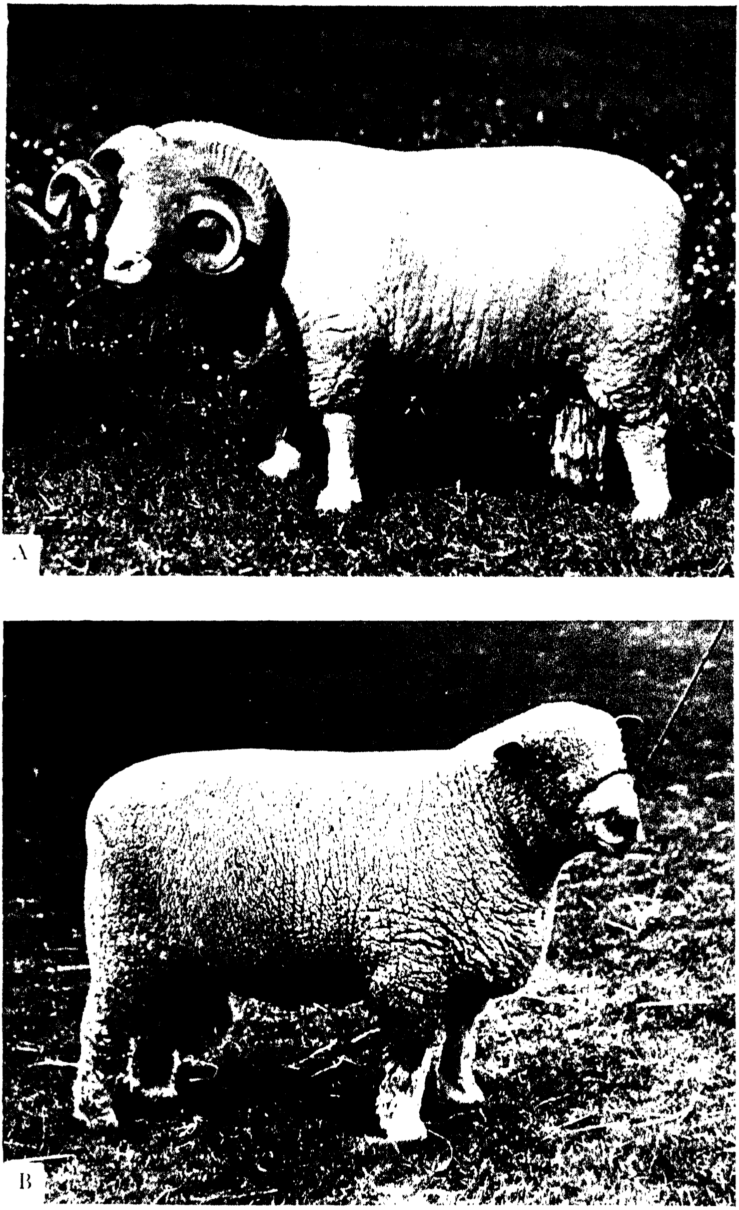
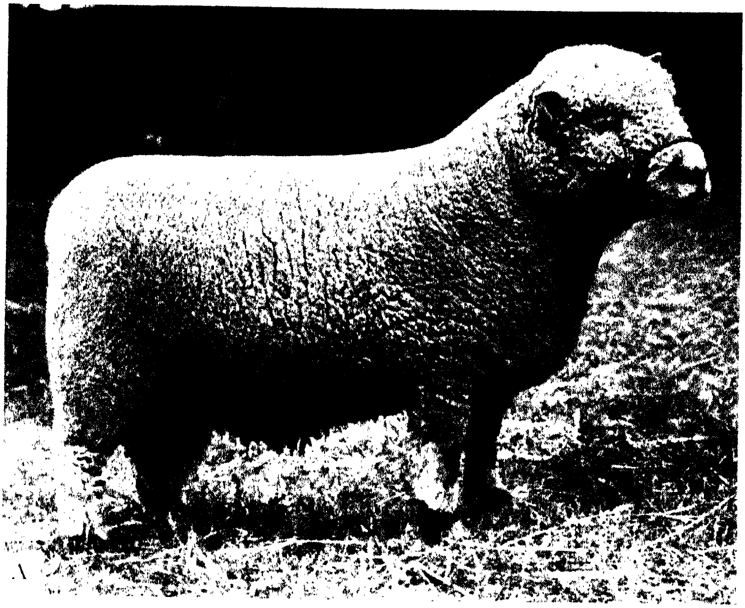


PLATE XLVII

A. Dorset Horn Ram

B. Ryeland Shearling Ram



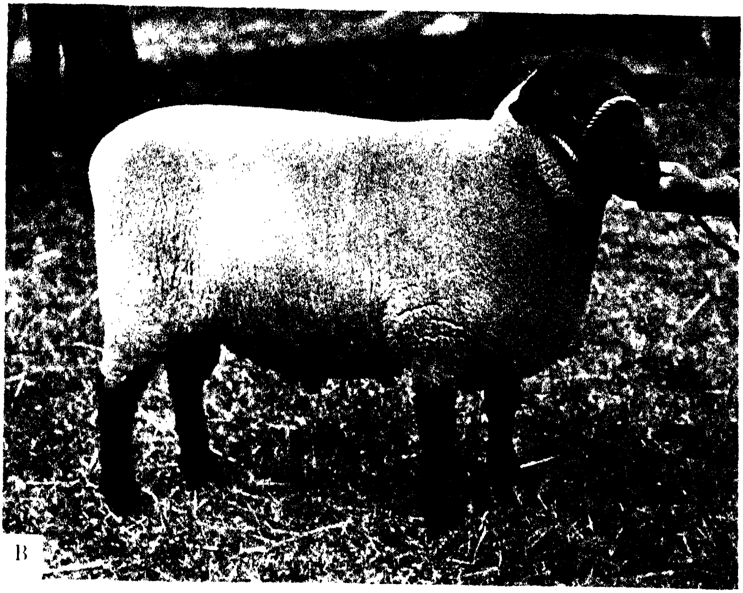
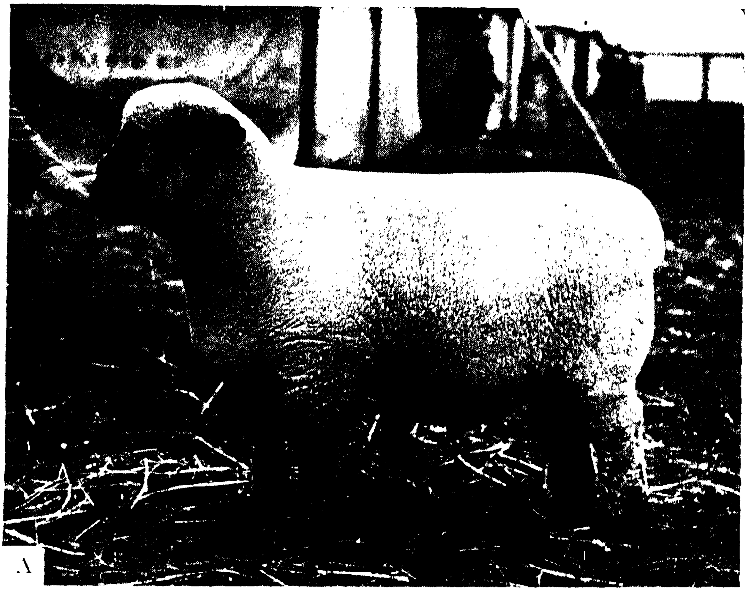


PLATE XLVIII
A. Southdown Ram Lamb
B. Suffolk Shearling Ram



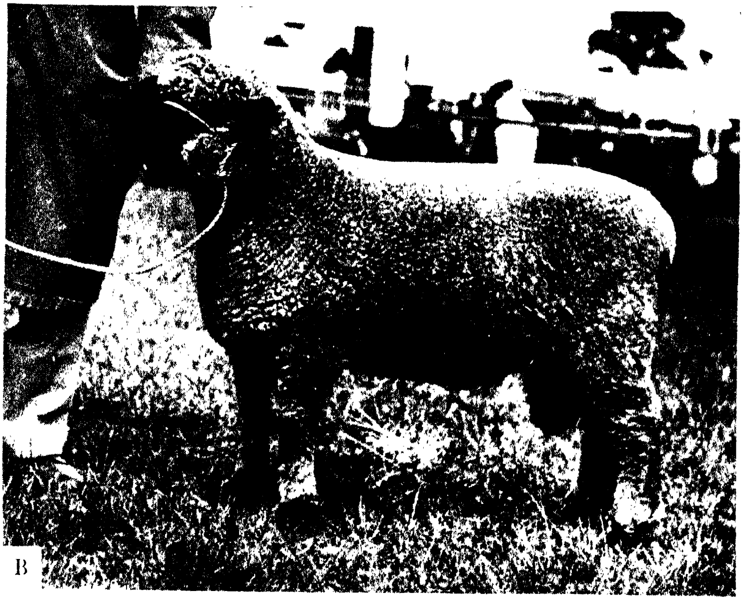


PLATE XLIX

A. Hampshire Down Shearling Ram

B. Oxford Down Shearling Ram

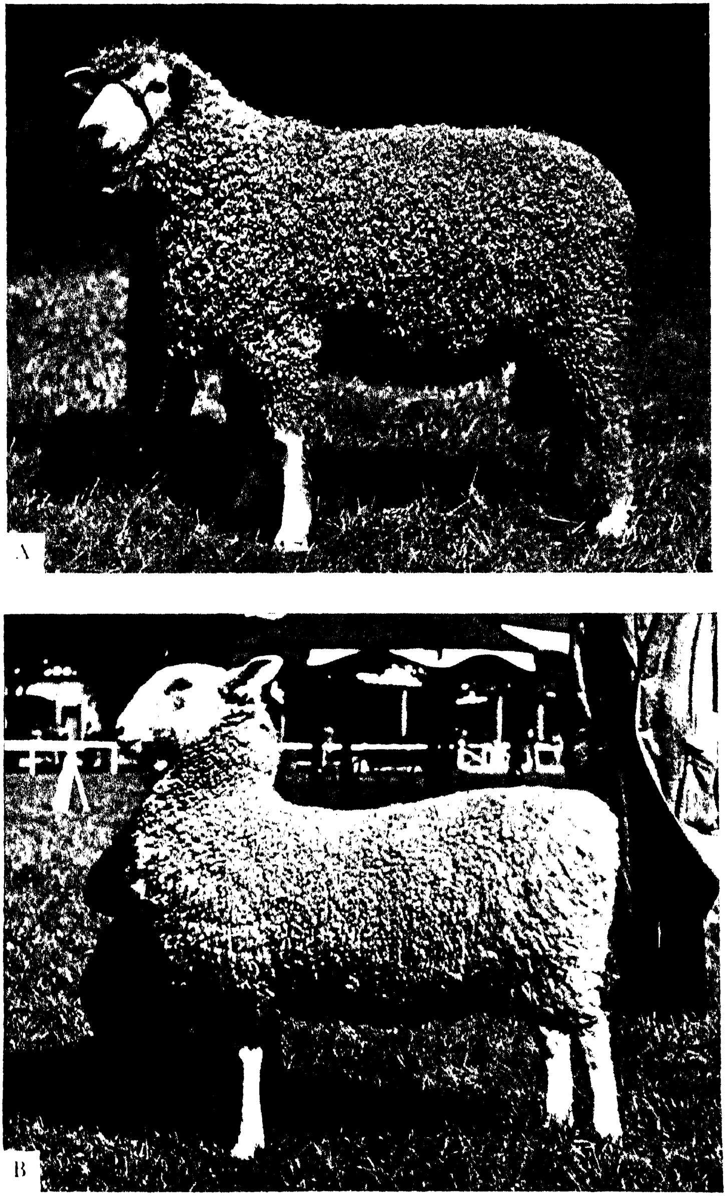
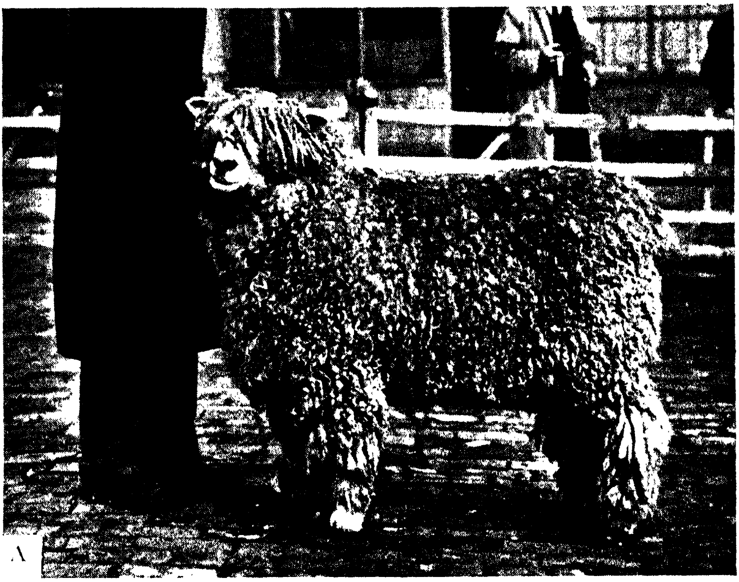


PLATE L

A. English Leicester Shearling Ram

B. Border Leicester Shearling Ram

A



B

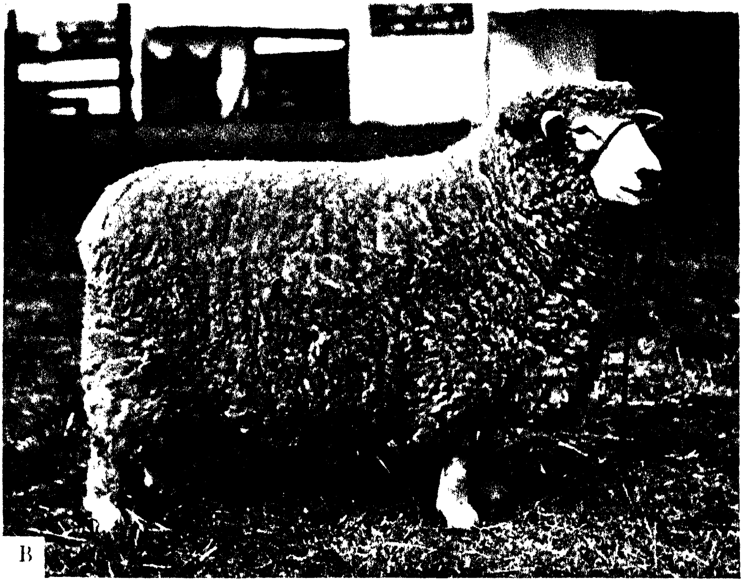


PLATE LI

A. Lincoln Longwool Ram

B. Kent or Romney Marsh Ram

must all be taken into consideration. In many flocks all ewes that have bred three crops of lambs are taken out for sale. Although they may be bred from for two or more seasons, they will if they are sound go to other farms which maintain " flying flocks ", i.e. flocks maintained by buying in for crossbreeding, no female progeny being retained for replacement.

In determining fitness for further breeding it is essential to examine the udder carefully to ensure that it is sound in both glands and teats. No ewes should be kept which show by poor condition and lack-lustre wool that they are unlikely to survive another pregnancy. In pure breeding flocks there should also be some selection for type and breed character, though the maintenance of these is governed largely by the quality of the young ewes drafted into the flock each year.

As a general rule ewes are mated for the first time to lamb their first crop at two years old ; a three-crop ewe is therefore four years old, showing a " full-mouthed " dentition, i.e. the eight permanent incisor teeth are up. In some late-maturing mountain breeds the first mating is postponed a further year. When culling is carried out all ewes should be " mouthed " to ascertain whether the incisor teeth are sound, because in the case of ewes which will have to consume roots during winter defective incisor teeth will be a severe handicap.

In the case of long-woolled types of ewe it is good practice to trim off some of the wool in the tail region before the rams are put with the flock.

Flushing. It is generally accepted that the potential breeding flock should be flushed before tupping. This implies a change to better grazing, or the provision of a special folding crop, and sometimes even the use of trough food. The purpose of flushing is twofold : it may increase the percentage of twins conceived and reduce the number of barren ewes but, more important still, by the stimulation of ovarian activity it will bring the ewes into season more uniformly so that the subsequent lambing season will be of shorter duration. This latter is a very important consideration, because a long-drawn-out lambing season gives too wide a spread in age of the lamb crop, though this can also be controlled by limiting to six or eight weeks the period during which the rams are left with the ewes.

Under certain conditions of management and environment a good proportion of twins is desirable, though for mountain and moorland ewes one lamb reared per ewe is the maximum—often the lamb crop does not exceed 60 per cent of the total breeding flock. But in measuring the fertility of a flock of ewes the figure taken is generally the number of lambs reared. If losses are heavy, even a high birth rate may result in an unsatisfactory rearage or final crop. Bad management and under-nutrition may lead to heavy losses in young lambs born too weak for survival, or receiving insufficient milk from their dams.

Number of Rams. The number of rams used is usually one for every 50–60 ewes in the flock, but there are two important considerations to be borne in mind—the age of the rams and the amount of range which the ewe flock will have. In the early maturing breeds most of the rams used are ram lambs of seven to nine months of age ; obviously older rams, shearlings and two shear, can be allowed to serve a larger number of ewes. But the amount of range over which the ewe flock can travel may render it necessary to turn out one ram to each 40 ewes else there may be a number of barren ewes, sterile because they were not found by the ram when they were in œstrum.

The œstrous cycle in the ewe is of 16–18 days in duration, the actual " heat period " lasting from 12 to 24 hours. It is a common practice to colour the rams on the breast when they are turned out so that all ewes served are marked ; by changing this colour after each 18-day period when the rams are with the ewes the progress of the flock mating is easy to observe ; if a large number of ewes is being marked more than once, a change of rams is essential. Another advantage of this marking is that it enables the ewes which will be the first to lamb to be picked out towards the advent of the lambing season.

Period of Gestation. The gestation period in ewes is normally 21 weeks, though a small proportion of the flock may produce lambs after 143 days of pregnancy. In large flocks the percentage of barren ewes may be 5 per cent, but this figure is often exceeded in flocks kept under environmental conditions where food is scanty and weather conditions unfavourable.

Precautions before Lambing. After the flock ewes are settled to the ram it is undesirable that they should be allowed to live too well, in fact during the first half of the gestation period no marked gain in live-weight should take place. But during the last eight weeks before lambing they should be managed well and adequately fed ; many losses occur before, during, and just after lambing because pregnant ewes have had unfavourable treatment. Undernourished ewes produce weakly lambs, which soon die from exposure, or such ewes will be short of milk and unable to rear their progeny. During the last weeks of pregnancy the feeding of excessive quantities of hay, chaff, and roots or kale will have a harmful effect, for as fœtal development in the uterus nears completion any overloading of the digestive tract with bulky foods should be avoided.

There are other ways in which lambing results are directly influenced by management. Ewes kept in folds on arable land may during wet weather have to lie in mud, and wet lying conditions are most unsuitable for ewes advanced in pregnancy. They should have access to drier ground at night even if they are feeding on a fold crop by day. Then there is the matter of exercise. This is necessary to preserve fitness and muscular tone before parturition; more bad lambings (i.e. difficult cases needing manual assistance) occur in flocks that have been so liberally fed with roots and hay that the ewes have not taken some daily exercise in foraging for themselves. It is also most important that no sudden changes in the diet should be made during the latter part of the period of gestation. A progressive improvement in the nutritive quality of the diet, with a reduction in its fibrous bulk, will do much to ensure a trouble-free lambing with no lack of milk supply in the ewes.

Lambing. The majority of flocks in this country are lambed in the months of March and April, though in the ram-breeding Down flocks, and in flying flocks kept for early fat lamb production, January and February are the busiest months. Adverse weather conditions play a big part in determining the actual crop of lambs born alive and subsequently reared. Plans should be laid in advance for this critical period in the flock's history, the primary considerations being food supplies and shelter.

Shelter. In well-sheltered lowland areas the provision of artificial shelters can be reduced to a minimum, but in exposed situations and on arable farms lambing in January and February it is usual to erect large lambing pens, using timber, wire, straw and hurdles. Small pens are provided for ewes newly lambed, and large pens for ewes heavy in lamb and those with lambs at foot. This elaboration allows the shepherd to give very close supervision during lambing and to ensure that all lambs are properly " mothered ". Under conditions of extensive range such close supervision is not possible and much daily walking is necessary for the shepherd if he is to keep the newly born lambs under close supervision. Motherless lambs are a serious problem for the shepherd to face but, with patience and ingenuity, he can foster them on to ewes that are orphaned, or he can take a lamb from a ewe with a twin or a triplet to give to a ewe that has lost her lamb. A really efficient shepherd in charge of an intensively managed flock will see to it that every ewe with milk and a sound udder has a lamb to suckle.

Apart from a heavy mortality due to bad weather, serious losses in newly born lambs can occur from an outbreak of that serious infectious disease, lamb dysentery. This is largely controllable by good hygiene and there is now a reliable method of prevention by the use of serum inoculation. Mastitis is sometimes a serious problem, but a more general use of the new drugs such as sulphapyridine can do much to bring ovine mastitis under control.

It is rarely that a flock can be lambed entirely without some bad cases needing manual assistance, and it is in this direction that shepherding efficiency varies greatly. The skilled shepherd knows when a ewe needs aid and he is careful and patient in the way he handles a ewe.

Tailing. The tailing of lambs is an important routine operation except in flocks of mountain and moorland breeds which, living under high altitude conditions, need tails as some protection for the udder region of the ewes. It may also be omitted in the case of lambs destined for early slaughter. Tailing can be carried out at any age from one week to three months ; lambs under six weeks of age will not lose too much blood if the tail is severed with a sharp knife, but lambs that are older should be docked with a docking or tailing iron, which is used hot, so that the tail vein and stump can be seared to prevent excessive loss of blood. Tails may also be removed by placing a small highly tensile rubber ring on the tail. This operation can be carried out when lambs are newly born : it should not be performed after the tail bones are well developed.

Castration. The castration of all male lambs not required as rams is another routine task usually carried out when tailing is done. There are three orthodox methods—drawing, castrating with clamp and the so-called bloodless method. The first of these is suitable for lambs under six weeks of age ; it involves cutting off the end of the scrotum and drawing each testicle away with a short portion of the spermatic cord attached. With older lambs this method may involve excessive bleeding and shock, so the use of a clamp to secure the ends of the spermatic cords after the testes have been cut off, and a hot iron to sear the cut surfaces, is the correct procedure. The " bloodless " method is now fairly widely practised ; in this a special type of pincer instrument is used to apply great pressure to the spermatic cords above the testes and no cutting of the scrotum is necessary. The pressure on the tissues of the cords destroys the connective tissues so that the testes gradually atrophy and disappear. This method is undoubtedly the most humane and the most hygienic, but unfortunately unless carried out by a skilled operator it is not always positive and many rig lambs may be left. If the bloodless method is practised a check examination of all wether lambs should be carried out after four weeks have elapsed so that further treatment can be given to those lambs which are rigs. Castration can also be effected by the rubber ring method : this involves placing the ring around the neck of the scrotum to cause atrophy of the entire scrotal sac.

Weaning. Weaning is the next routine operation, and this usually takes place when the average age of the lambs is four months. It means nothing more than the separation of the ewes from their progeny and, if possible, segregation of the lambs out of earshot. The ewes should be relegated to poorer keep to hasten the drying off of milk secretion, and some observation of their udders is necessary at this time because some ewes may be overpent with milk. Ewes which after weaning develop udder trouble will have to be culled from the future breeding flock since their useful breeding life is over.

Shearing. One of the most important operations of summer sheep management is shearing or clipping. As a prelude to this in all well-managed flocks the ewes are crutched or tail trimmed ; this means the removal of all soiled wool from the tail and breech region. The time of shearing varies according to locality. In the south of England, and at low elevations, it is usually carried out in June, but on high land and in the north July and August are the busiest months for this work. It cannot be done until the yolk has risen in the fleece and this does not take place until warm weather promotes the rise in the wool. Clipping with hand shears still predominates as the method of removing the fleeces from the lighter-bodied mountain breeds, but in lowland areas machine shearing has become increasingly popular. A skilled operator will shear 70–100 sheep in a day, though in the sheep-raising countries of the southern hemisphere, through greater specialisation of labour, a much faster rate of shearing obtains. It is most important to keep extraneous dirt and soiled locks from the shorn wool. The fleeces should be rolled and tied before packing in special wool sheets. In this country little attempt has been made to sort and class the wool before packing, whilst in the great wool-exporting countries this is done with great thoroughness.

The sale of all British wool is now controlled by a Wool Marketing Board. Prices have become more stabilised, and much progress has been made in the direction of eliminating the faults in handling and presenting wool for sale by the imposition of price reductions for tar stain, faulty fleeces, and the inclusion of tailings with sound wool in packing. The sale value of British wool can be much enhanced by the attention each individual wool producer gives to the handling and packing of wool at shearing time.

Washing. Up to the early part of the present century it was the usual practice to wash sheep before shearing ; this meant immersion of the animals in a running stream in order to rid the wool of dirt and other impurities. This practice has to a large extent been abandoned because the slightly higher price paid for the washed wool is offset by a loss in weight. The buyers of English wools have developed the process of scouring to a high degree, and in this process a valuable by-product—the natural wool grease—can be extracted.

Whilst for most sheep their first shearing takes place in their second summer of life, some shearing or clipping of lambs is carried out in certain breeds and in the southern half of England.

Yield of Wool. The weight of wool yielded annually by adult sheep varies from 3–4 lb. in the case of the smaller short-woolled breeds to 12–16 lb. in the case of longwools. Well-fed rams will yield amounts of wool much in excess of these amounts.

After shearing or clipping has taken place the shepherd will find the supervision of the flock less arduous ; there is a reduced chance of maggot-fly strike in the shorn sheep, this being one of the major afflictions of sheep during the summer months, especially in flocks kept on land below 1,000 feet in elevation (see p. 449).

Dipping. The next summer task is dipping, usually carried out about a fortnight after shearing. Dipping is a compulsory practice enforced by statutory order in every county, though there is some variation from district to district as to the period when dipping must take place and also as to frequency. Some parts of the country are scheduled as " double dipping " areas, whilst in others, e.g. the south and south-east, only one dipping during the statutory period is obligatory. The principal reason for the enforcement of dipping regulations is the control of sheep scab. But other external parasites of sheep, such as the maggot-fly, the ked, the sheep tick, and the sheep louse are all kept under control by dipping (see p. 451) ; a sound standard of flock hygiene cannot be maintained without the practice of dipping.

Owing to the virtual elimination of Sheep Scab in England there is now a tendency to relax compulsory dipping in certain counties. But the need to control external parasites in the wool of sheep is as great as ever. To do this the labour-saving practice of spraying is becoming more widespread. Though it involves the installation of special equipment, it does reduce the amount of dip fluid necessary to treat large flocks. During the statutory dipping period no sheep may be sent to any market fair unless they are accompanied by a declaration that they have been dipped and kept isolated from undipped sheep.

This is the last of the major operations in the routine management of a flock, though other tasks may be necessary to maintain the flock in good health. A shepherd should be always on his guard to prevent the spread of lameness through footrot ; and periodic drenching to control parasitic worms may also have to be carried out at certain periods. In the management of sheep much depends upon the accurate daily observation of the flock by a shepherd or flockowner who is able to perceive any departure from normal health and well-being. The prompt diagnosis and treatment of certain ailments will prevent losses by death or lack of thriving.

On farms which carry medium- and large-sized permanent flocks, much time and labour can be saved in handling, drafting and dipping by the provision of fixed equipment of good design. Even the operation of dipping can be made possible for one man by the installation of a side slide-in device in lieu of the direct plunge method which involves handling individual sheep. In the large sheep-raising countries of the Southern Hemisphere, specialised sheds for shearing and handling wool are essential equipment. Flock sizes in this country do not always justify a heavy capital outlay in fixed equipment for handling sheep, but the rise in cost of labour now makes it imperative that some well-planned lay-out for handling and sorting sheep is available on farms which have a sheep-raising policy.

CAUSES OF LOSS IN SHEEP

Many diseases of sheep cause actual death, and while others may not be fatal they can and do cause loss of condition ; more than this, they bring about the need for more labour in the tending of sheep. Blow-fly attack and footrot are examples of ailments peculiar to sheep which can greatly add to the labour of shepherding, and in the case of the former, failure to give effective treatment may ultimately result in death. The wide-scale use of the newer insecticidal compounds in dip preparations and as sprays makes the control of sheep maggot flies much easier than in the past.

Lameness through footrot is a very common affliction of sheep, especially in areas of low elevation and high rainfall. Recent research in Australia has shown that footrot is caused by a bacterium ; the disease is highly contagious but does not persist for any length of time in the soil. Certain animals which have a chronic degree of infection act as carriers and these should be eliminated from the flock. Footrot can be cured by paring the diseased tissues away from the hoof and passing sheep through a footbath containing some antiseptic preparation such as formalin or copper sulphate in solution.

The external parasites of sheep, in addition to the blow-flies, are lice, ticks, keds and the sheep scab mite. All these are easily and effectively controlled by sound dipping practice.

Sheep are subject to a wide variety of internal parasites. The liver fluke, stomach and intestinal worms, and husk and lung worms annually cause a heavy loss through unthriftiness and actual deaths. The liver fluke can be avoided by keeping sheep away from pastures in which there is stagnant water harbouring the small grey water snail, and dosage with carbon tetrachloride is effective in treating fluky sheep. The various types of roundworm causing parasitic gastritis and parasitic bronchitis become prevalent whenever sheep are grazed thickly and frequently without change of pasturage. Systematic management of grazing, the use of other classes of grazing stock, especially cattle, will do much to prevent serious worm infestation. Routine drenching with the newer vermicides such as phenothiazine can do much to reduce losses from parasitic gastritis ; none the less, it should be remembered that the over-concentration of sheep in grazing will always result in re-infestation.

Sudden deaths in fast-thriving adult sheep and in young lambs can often be ascribed to bacterial activity in the bowel resulting in rapid toxin formation, causing death from entero-toxæmia in older sheep and from pulpy kidney in lambs. Such losses can now be prevented by vaccine treatment.

Many young lambs die annually from exposure and disease. Navel ill, tetanus and lamb dysentery are the more serious diseases ; there is now an effective serum treatment for lamb dysentery so that this disease is no longer a serious menace.

In breeding ewes losses may occur from pregnancy toxæmia (twin lamb disease), mastitis, milk fever and hypomagnesaemia. Sometimes septic metritis after lambing proves fatal. Correct nutrition and good hygiene in the lambing season will do much to counter these causes of loss.

Other sheep diseases not infrequently met with in some parts of Britain are braxy, scrapie, louping ill, and tick borne fever. But for these, serum or vaccine treatment can be used with considerable success. Further information about diseases of sheep can be found in Chapter XXIV.

It is necessary to note before leaving the subject of sheep diseases that mineral deficiencies in the herbage are all too common in some areas of high rainfall, especially on land of high elevation. Undoubtedly these deficiencies predispose sheep to disease and ailments of many kinds. Recent work has shown that the feeding of mineral mixtures containing copper salts has been effective in reducing losses from " swayback " in lambs in north Derbyshire. It is also highly probable that deficiencies of other elements such as copper, iron, manganese, cobalt and zinc are, in certain districts, the cause of ill-health in sheep—particularly in reducing their resistance to parasitic infestation. Much of our grazing land is very deficient in lime and phosphates ; in fact, these may be described as major deficiencies. Research work in the Border counties and in Scotland has now convincingly proved that the use of complete mineral mixtures has a marked influence on ovine health and vitality. No doubt our knowledge of this subject will be much advanced during the next decade ; a great deal of important work still remains to be done.

SYSTEMS OF SHEEP FARMING

The wide range of environmental conditions under which sheep can be kept in this country is reflected in the great variety of British breeds and crossbreds of commercial value. It is always possible to select a pure or crossbred type of sheep that will adapt itself to any farming system and to land of any level of fertility.

Farms on which sheep form either the whole or a part of the livestock enterprise can be classified as follows :

1. Mountain and moorland areas of high elevation.
2. Hill sheep farms.
3. Upland farms mainly pasture.
4. Upland farms mainly arable.
5. Lowland mixed farms.
6. Lowland farms mainly pasture.

1. **Mountain and Moorland Farms.** In Wales, northern England and Scotland there is much land over 1,500 ft. in elevation which is used to maintain breeds such as the Welsh Mountain, the Herdwick, the Swaledale and the Scotch Blackface. Individual sheep farms are often very extensive in area and boundary fences may be non-existent ; when a farm has a change of occupier the flock remains because it is important to maintain stock acclimatised to the area. Formerly some of the sheep stock on this high land consisted of two-, three- and four-year-old wethers which yielded an annual clip of wool to pay for their maintenance ; but now the sheep stock consists mainly of breeding ewes, with their followers during the summer months. After three breeding seasons the ewes are drafted and sold, passing to farms of lower elevation for a further year or two of breeding. The climatic conditions and sparse grazing on this high land make it essential that all lambs are brought away from the mountain land during autumn, the wether lambs being sold for feeding in the lowlands whilst ewe lambs which will be needed for flock replenishment have to be wintered away on better land, returning in the following spring.

The lamb crop on these farms is much influenced by weather conditions. Severe snowstorms in the winter may cause heavy losses in ewes and, although lambing does not take place until April and May, many lambs may be lost through exposure. In a good season the lamb crop per 100 ewes seldom exceeds 80 per cent ; in a bad year it may be as low as 40 per cent.

2. **Hill Sheep Farms** may be defined as those at an elevation of 900 to 1,200 ft. Breeds such as the Cheviot, the Exmoor and the Kerry Hill may be regarded as typical for this class of land. Owing to a more favourable environment the yield of lambs on farms in this class is higher. A greater proportion of the grazing may be enclosed, affording the opportunity for better control of grazing, whilst supplementary food for winter-spring use can be more easily obtained and fed.

3. **Upland Pasture Farms.** On upland farms which are mainly pasture, sheep of the hill breed class have been extensively used. Farms in this category only differ from the hill farms in that all the area is enclosed and the land is at an elevation below 900 ft. which permits some arable cultivation ; this means that a small root break can be provided each year to produce roots for feeding in the early spring when pasture growth is scanty. During the decade prior

to 1939 much land on the drier uplands of the oolitic and chalk geological formations was devoted to this type of sheep farming, pure and crossbred sheep of great variety being used, such as Cheviots, Exmoor, Kerry Hills, Ryelands and numerous crossbreds. The rate of stocking with sheep on such farms, if they maintained few or no cattle, was too high to ensure the maintenance of a satisfactory standard of health among sheep after two or three years. The drier uplands do not maintain a good type of pasture sward if grazed mainly by sheep, for herbage quality deteriorates owing to excessively hard grazing in the spring months and excessively close grazing during periods of summer drought inevitably leads to serious stomach worm infestation.

4. **Upland Arable Farms.** No system of sheep farming has shown a greater decline during the past half-century than the arable system, which was practised very extensively on the upland, mainly arable, farms on the chalk and limestone formations of the South and South Midlands and in East Anglia and on the Yorkshire Wolds. The system involves the intensive management of sheep with extensive arable farming. Throughout the whole year flocks lived on a succession of crops grown for them on the tillage area, each day a fresh fold or pen being set up with hurdles to allow the flock access only to an amount of crop which would be consumed daily. During winter, large amounts of hay and trough food were used to supplement the fold crop, and by this means a very high rate of sheep stocking per acre was maintained without risk of disease. On light and friable arable soils it was found that the treading and manuring by sheep resulted in a satisfactory level of yield from the subsequent cereal crops. When this arable system was at its zenith artificial fertilisers were not widely used but oilcakes were cheap and abundant—they were often wastefully used because of their manurial value to succeeding crops.

In their tolerance of close folding on arable crops our Down breeds and the Dorset Horn are quite unique. Although there has been such a marked decline in arable sheep farming for a variety of reasons—mainly economic—it is still carried out in several counties, particularly in pedigree flocks which specialise in ram breeding. The arable farm with its succession of tillage crops is able to cater for a ewe flock lambing in January to produce fat lambs for the Easter trade, and well-grown ram lambs for the summer and early autumn trade. A typical feeding programme, from January onwards, would be as follows : swedes ; swedes and kale ; winter barley or rye ; trefoil or trifolium ; vetches ; clover lattermath ; rape, and in December, turnips.

The arable system with all-the-year-round folding is costly in labour, cultivations and equipment.

5. **Lowland Mixed Farms.** On lowland mixed farms sheep can be kept with profit if well managed, provided that they do not encroach on land suitable for dairying. Soils of the lighter type are desirable because during the winter months the flock can be penned on arable crops, sugar beet tops, turnips, swedes and kale. From the time when growth is abundant on leys and pastures, i.e. early May until the

late autumn, no folding is necessary if all fields are fenced and watered and the flock can be grazed. This mixed-farm system of sheep management has much to commend it from the standpoint of disease control, since leys and pastures are rested from sheep grazing during several months of the year so that stomach and lung-worm infestation is to a large extent avoided.

6. **Lowland Grass Farms.** Except in localities unsuited for bullock feeding or dairying, sheep are not extensively kept on lowland grass farms. The reason for this is not hard to find—sheep are not so well suited to lowland grazing as are cattle. They are easily subject to footrot when kept on heavy damp soils, and in badly drained areas they may acquire liver fluke. In the whole of Britain there is only one large area of low elevation land heavily stocked with sheep—the Romney Marsh.

For lowland grazing on rich land the large long-woolled breeds are preferable to other types. It is one of the essential points in sound sheep management that the type of sheep kept should be correctly related to the productivity of the land. For mixed farms of average fertility the Half-bred (Border Leicester × Cheviot) or its crosses by a Down-breed ram will always maintain a high standard of lamb output. To put sheep of a large breed on poor land is a bad mistake, and it is equally wrong to put sheep of small size, accustomed to hard living, on to grazing of high productivity.

FLOCK SYSTEMS

Many farms maintain a permanent breeding flock of ewes in regular ages. This means that each year the oldest age group of ewes is drafted out and flock numbers are made up by introducing a sufficient number of young ewes to make up the flock number, these young ewes being either home bred or purchased. The draft ewes sold will, if sound, go to other farms for further breeding for one or more seasons. It is usual to cull out draft ewes from permanent breeding flocks after they have bred three or four crops of lambs. This practice is sound because the capital value of the flock is maintained so long as numbers are constant.

Another system is the maintenance of a flying flock, i.e. one which is bought in and then sold out, spending less than one year on the farm. Three kinds of flying flock can be kept : draft ewes for breeding ; store lambs for fattening ; or ewe lambs bought in to be grown on for subsequent sale as young breeding ewes. The flying breeding flock has often in the past been associated with dairy farms where the cattle are housed in winter, and the ewe flock is used to clean up the ungrazed growth on pastures in winter.

An assured market for the flesh of sheep, and for the wool they produce, will in the near future result in the introduction of sheep to many more lowland farms which are adequately fenced. On milk producing farms, and on farms producing cash crops such as sugar beet, a small flock of breeding ewes can add substantially to the gross farm revenue, without necessitating a heavy capital investment in specialised buildings.

SHEEP FEEDING

No other class of livestock is so difficult to feed according to exact feeding standards. It is possible, however, to state approximate quantities of food consumed by sheep of medium size. On grazing land five adult sheep can be considered equivalent to one bullock. With regard to hay, if no other food is given, an adult ewe of average size will consume 3–5 lb. daily, but hay is generally fed as a supplement to other foods in the diet, allowing from ½–1 lb. daily. When roots are fed the consumption will depend upon the amount of hay given, if any, and upon the trough food available; ewes of 140 lb. live-weight will easily consume 14–20 lb. of roots daily.

In the days when imported concentrates were plentiful and cheap they were extravagantly used in sheep feeding on some farms. Their liberal use can now only be justified in early, out-of-season, fat lamb production and to bring forward well-grown pedigree rams for the autumn sales. An allowance of over 1 lb. of trough food per sheep per day must, under present-day conditions of price, be considered generous.

The problem of how to obtain an adequate supply of protein as a supplement to roots in winter feeding is now a serious one. It can be best solved by making hay of better quality, and by a greater extension of silage making to conserve for winter use the high protein content herbage from our pastures and leys, which is usually in plentiful supply during May and early June.

Further information on feeding problems is given in Chapter XVIII.

THE NOMENCLATURE OF SHEEP

There is much variation in the terms by which sheep are described in different localities. The following table is a summary of the terms most commonly used:

MALES.		FEMALES.
Entire.	Castrated.	
Ram lambs	Wether lambs	Ewe lambs, Gimmer lambs, Chilvers
Hogg rams	Wether hoggs	Ewe hoggs
Ram hoggetts	Wether hoggetts	Ewe hoggetts
Teg rams	Wether tegs	Ewe tegs
Diamond tups		
Shearling rams	Shearling wethers	Shearling ewes
Shearling tups		Gimmers
		2-tooth ewes
Two-shear rams		One-crop ewes
Two-shear tups		4-tooth ewes
		Two-crop ewes
		6-tooth ewes
		Three-crop ewes
		Full-mouthed ewes

The teeth referred to are the permanent incisors of the lower jaw which replace the temporary incisors at approximately the following ages :

Age.	Eruption of Lower Permanent Incisors.	Definition of Ewe.
12–18 months	central (2)	2-tooth
18–24 months	outer middle (2)	4-tooth
30–36 months	outer (2)	6-tooth
36–48 months	corner (2)	Full mouth

The value of breeding ewes is much influenced by age since that denotes capacity for further breeding if the udder is sound. The dentition standard is a fairly reliable one when a seller is not prepared to give a warranty as to the number of seasons a ewe has been lambed (see also p. 497).

MARKET DEMAND

Lamb is now in much keener demand than mutton : smaller joints, chops and cutlets are the order of the day. More important still is the consumer's aversion to excessive fat in meat. Hence it is essential that producers of lamb and mutton should sell their stock at the right weight and at the correct degree of finish, i.e. adequate fleshiness with no excess of fat. The future prosperity of our sheep industry will depend upon more consideration being given by producers to consumers' choice.

Chapter XXII

PIGS

THE DEVELOPMENT OF PIG HUSBANDRY

THE practice of pig husbandry is of great antiquity, the earliest known reference being to the small active pig ranging the woodlands in the Neolithic Age. The Roman writers make numerous comments on pigs, and in Saxon times large herds were kept. After the Norman Conquest every household had its pigs and the village swineherd was responsible for their care. Throughout Tudor times large numbers of pigs were kept, sties being built to house them, but they were still turned out to the woods and waste grounds during the day. Litters of eight pigs reared were considered good, but those of three to five were common.

During the eighteenth century considerable improvement in pigs was effected. Bakewell began to select the Large White in 1760, and the Chinese pig was imported between 1770 and 1780. This crossed with the native breeds gave earlier maturity and better fleshed carcases. Pig keeping in association with dairying developed. By 1850 pig shows and the classification of individual breeds had arrived. These shows played a very important part in the development and improvement of the pig. In 1884 the National Pig Breeders' Association was formed and in 1898 the Large Black Pig Society came into being. During the early years of the present century many other breed societies were founded; there was much active work on technical aspects of pig production; breeding, feeding and housing were steadily improved, and the marketing of bacon pigs was put on a sound basis.

Since the industrial revolution in the middle of the nineteenth century, and the resulting demand for large supplies of food of all kinds for a population turned mainly urban, there has been an increasing trade in pigs and pig products.

In 1932, a Re-organisation Commission for Pigs and Pig Products was set up to prepare a scheme for regulating the marketing of pigs and pig products, with the object of offering to the home producer a market for his products at a price which would provide a reasonable profit for efficient production. The recommendations of this Commission resulted in the formation of the Pigs Marketing Board and the Bacon Marketing Board in 1933. Thus the marketing of bacon pigs was regulated, while pork pigs still had a free market.

There is no doubt that the grading of bacon carcases under the Marketing Board which operated from 1933 to 1939, and of pork carcases under a voluntary scheme instituted in 1933 by the Ministry of Agriculture and Fisheries, together with the carcase competitions organised by breed and show societies, did a great deal to raise the quality of both bacon and pork carcases. Then came the Second World War.

Early in 1940 the Ministry of Food became the sole purchaser of all fat pigs and the main activities of the two marketing boards were suspended, never to be revived. Emphasis was placed on weight so as to secure the maximum weight of pig meat from the limited food available, and as a result quality deteriorated. It was not until 1950 that the production of heavy pigs was discouraged and not until 1953 that any form of grading of carcases was re-introduced. Lighter weights for pork pigs attracted a higher price from April, 1953, but no quality premiums were paid for pork.

Controls for the marketing of fat stock ceased in July, 1954 and at the same time the Ministry of Food ceased to purchase fat pigs. There were objections to the revival of the marketing boards, and the National Farmers' Unions established the Fatstock Marketing Corporation (F.M.C.) to deal in all types of fat stock, including pigs. Since July, 1954, the majority of bacon pigs have been sold through the F.M.C., whereas pork pigs have gone through the auction markets. Under the Agriculture Acts of 1947, pig products are included in the general system of guaranteed prices. Payments are made to farmers based on the difference between the market price of pigs and the guaranteed price. These deficiency payments as they are termed have been substantial.

In 1955 an Advisory Committee on the Development of Pig Production had reported, and in 1956 an Agricultural Marketing Reorganisation Commission published a report on the pig industry. In a White Paper issued in November, 1956, the Government indicated its views on policy after consideration of these two reports. It agreed with the view of the Commission that a basically free market in pigs and pigmeat was preferable to a marketing board for all pigs, especially as an effective service to producers was being provided by voluntary co-operative organisations such as the F.M.C. It also accepted the recommendation to establish a Pig Industry Development Authority and legislation established this Authority on October 1, 1957.

The Pig Industry Development Authority (P.I.D.A.) does not buy or sell pigs or pig products and is not concerned with marketing arrangements. It has power to take action in " improving efficiency in production, marketing and distribution of pigs and the production, processing, manufacture, marketing and distribution of pig products and improving the quality of pigs and pig products." Towards these ends the Authority has promoted or undertaken such things as pig recording, progeny testing, accreditation for breeding herds, artificial insemination and research on the pig husbandry side of its activities.

In bacon production, the home farmer is exposed to strong competition from a number of countries notably Denmark and, to a lesser extent, Holland and Poland. Competition in the pork market is not so great, imports of fresh and frozen pork being relatively small. In the sale of breeding stock there is virtually no external competition, but internal competition is strong. It is clear that the pig producer must do everything possible to breed and feed animals capable of producing economically high quality carcases and the need for this is emphasised in the price structure for bacon pigs.

BREEDS

Hammond has demonstrated that different types of pigs tend to reach the desired carcase conformation at different weights. The early maturing breeds produce this at approximately 100–120 lb. live weight, the late maturing breeds at 200–210 lb. live weight. It is thus convenient to consider individual breeds in relation to their rate of maturity. The choice of any particular breed is determined mainly by three factors, viz. the purpose for which it is intended, the personal preference of the owner, and local custom.

Much more important than breed is the selection of a good strain within the breed chosen. The fact that an animal is a pedigree animal is some guarantee of its breeding, but while a pedigree pig is preferable to one of unknown ancestry because it will breed true, it does not follow necessarily that it is a good animal or that it is backed by satisfactory performance. Until pig recording and especially progeny testing have been further developed information on performance is of necessity limited, but it is important to find out as much as possible of the ability of the strain selected to breed, rear and fatten pigs of the desired type and quality.

EARLY MATURING BREEDS

The Berkshire was one of the first breeds to have a recognised herd book, and it is a typical pork breed. It is not widespread in this country but is of considerable importance in the United States, Canada, New Zealand, Australia and Argentina (Plate LIIIB).

The Middle White is well suited to the small pork trade, and boars of this breed have been used for crossing with other breeds for pork production. The breed matures rapidly, is hardy, and is capable of economic meal consumption (Plate LIIB).

LATE MATURING BREEDS

The Landrace has achieved high reputation for the quality of bacon produced and for economic production. In Denmark and Sweden it has been selected carefully over many years under detailed progeny testing methods. Selected specimens of the Swedish Landrace were imported into Great Britain in 1949 and 1953 and the breed has spread with great rapidity. Whether because of this rapid spread the breed has suffered deterioration remains to be seen, for in this country it was not subjected to intensive progeny testing after importation (Plate LVB).

The Large White has a world-wide reputation. The Large White boar is regarded throughout the world as eminently suitable for crossing with other breeds for bacon production and is invaluable for grading up inferior herds. Bred pure, it is capable of producing bacon of the finest quality, and a long record of success in carcase competitions demonstrates this important characteristic (Plate LIIA).

The Welsh has become more widely distributed during the past twenty years. It has the merit of being white in colour and can be bred pure for bacon production, although Welsh sows are frequently crossed with Large White or Landrace boars. It is hardy and prolific, but as yet has not achieved outstanding success in carcase competitions.

MEDIUM MATURING BREEDS

The Essex, Gloucester Old Spot (Plate LVA), Large Black (Plate LIIIA), and Wessex Saddleback (Plate LIVA) breeds are all intermediate in character. Mated to boars of the Large White type they are capable of producing pigs for both the pork and bacon markets. They each are prolific and the sows have a high reputation as careful mothers. In commercial pig production, the crossbred pigs are valued for their hybrid vigour and the so-called " blue " pig obtained from some of the breeds is popular with feeders.

With the exception of the Tamworth (Plate LIVB) which is kept in comparatively small numbers in this country but has an excellent reputation in Canada and New Zealand, the remaining breeds in this country are mainly of local interest. These are the Cumberland, Large White Ulster, Long White Lop Eared, and Dorset Gold Tip.

Descriptive brochures on individual breeds may be obtained from breed societies.

STANDARDS OF EXCELLENCE

The breed societies have prescribed standards of excellence for each of the breeds under their control. Apart from points such as colour markings, set of ears, and variations in length of head, these standards are all on similar lines. That published by the National Pig Breeders' Association for the Large White breed is given below as an example.

Head	Moderately long, face slightly dished, snout broad, not too much turned up, jowl light, wide between the ears.
Ears	Long, thin, slightly inclined forward, and fringed with hair.
Neck	Long, fine and proportionately full to shoulders.
Chest . . .	Wide and deep.
Shoulders . .	Level, obliquely laid, medium width, free from coarseness.
Back	Long, level and wide from neck to rump.
Loin	Broad.
Quarters . .	Long and wide.
Hams	Broad, full and deep to hocks.
Tail	Set high, stout and long, but not coarse, with tassel of fine hair.
Ribs	Well sprung.
Sides	Deep.
Belly . . .	Full, but not flabby, with straight underline and with at least twelve sound, well-placed teats.
Flank . . .	Thick, and well let down.
Legs	Straight and well set, level with the outside of the body, with flat bone.
Pasterns. . .	Short and springy.
Feet	Strong and even.
Action . . .	Firm and free.
Skin	Fine, white, free from wrinkles, black hairs and black spots, and as free as possible from blue spots.
Coat	Long and silky.

PIGS IN THE FARM ECONOMY

Pig keeping is practised on many varied types of farms and in a wide range of intensity. It is associated (*a*) with the main arable areas in the country where pigs are used to consume the main by-

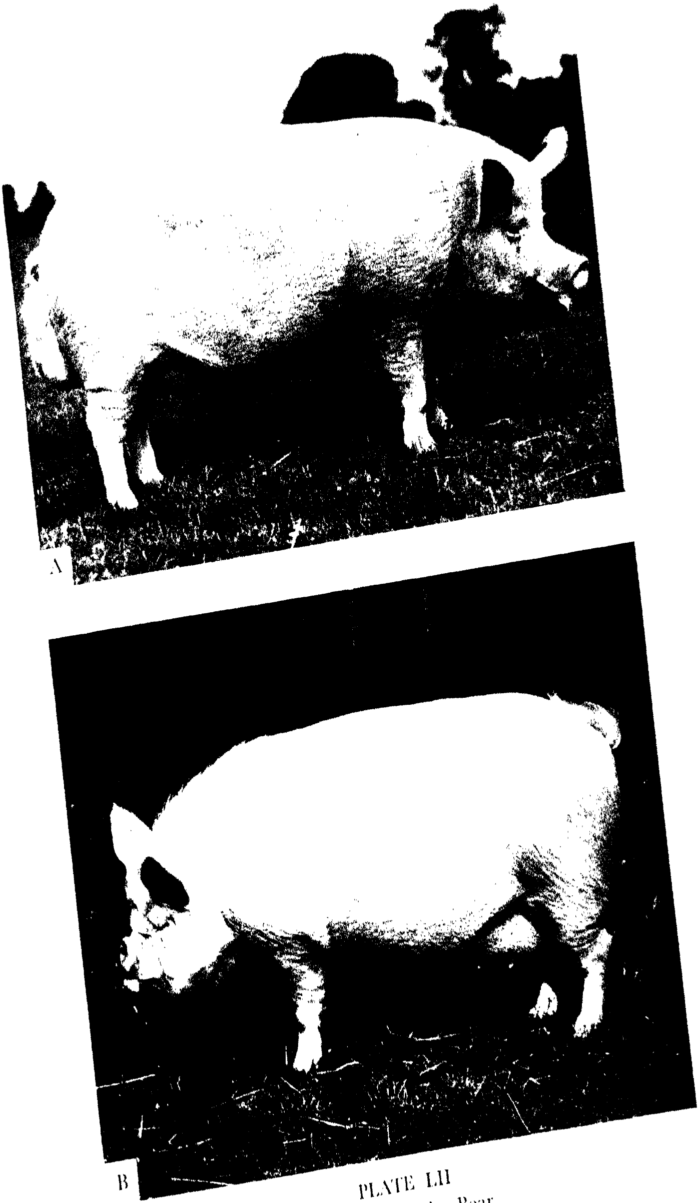


PLATE LII

A. Large White Boar

B. Middle White Boar

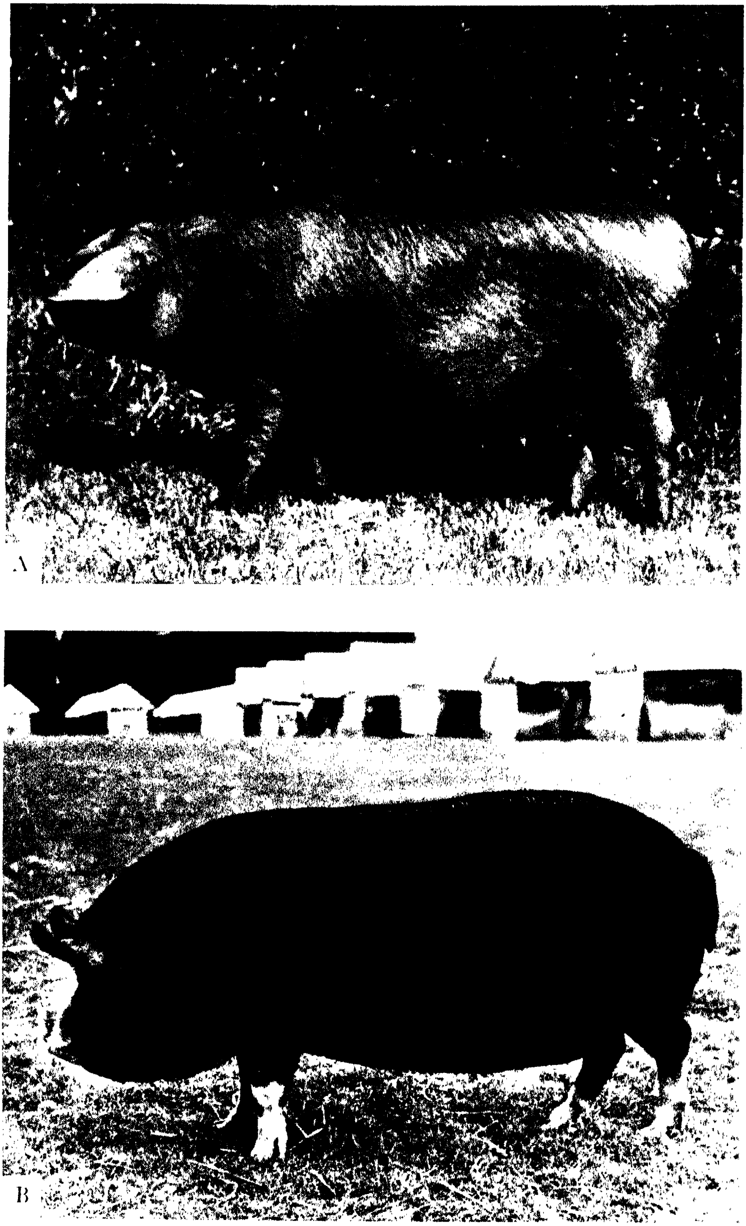


PLATE LIII

A. Large Black Sow

B. Berkshire Sow

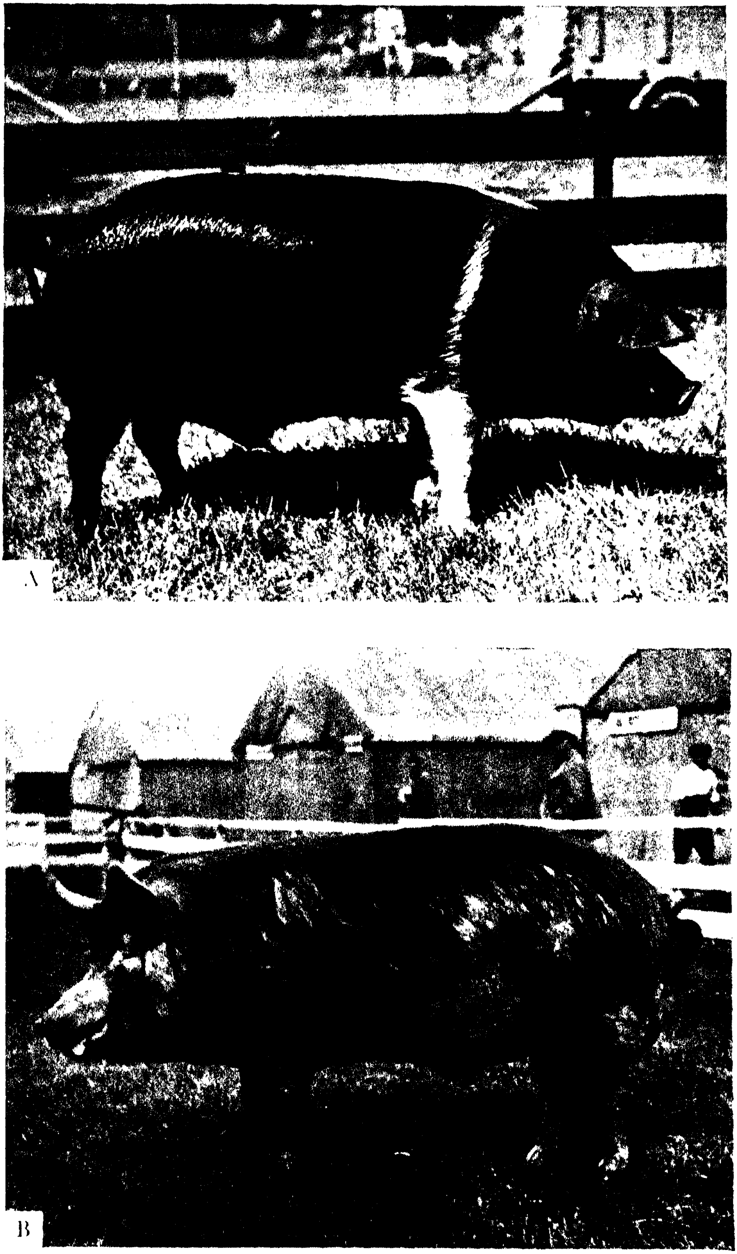


PLATE LIV

A. Wessex Boar

B. Tamworth Boar

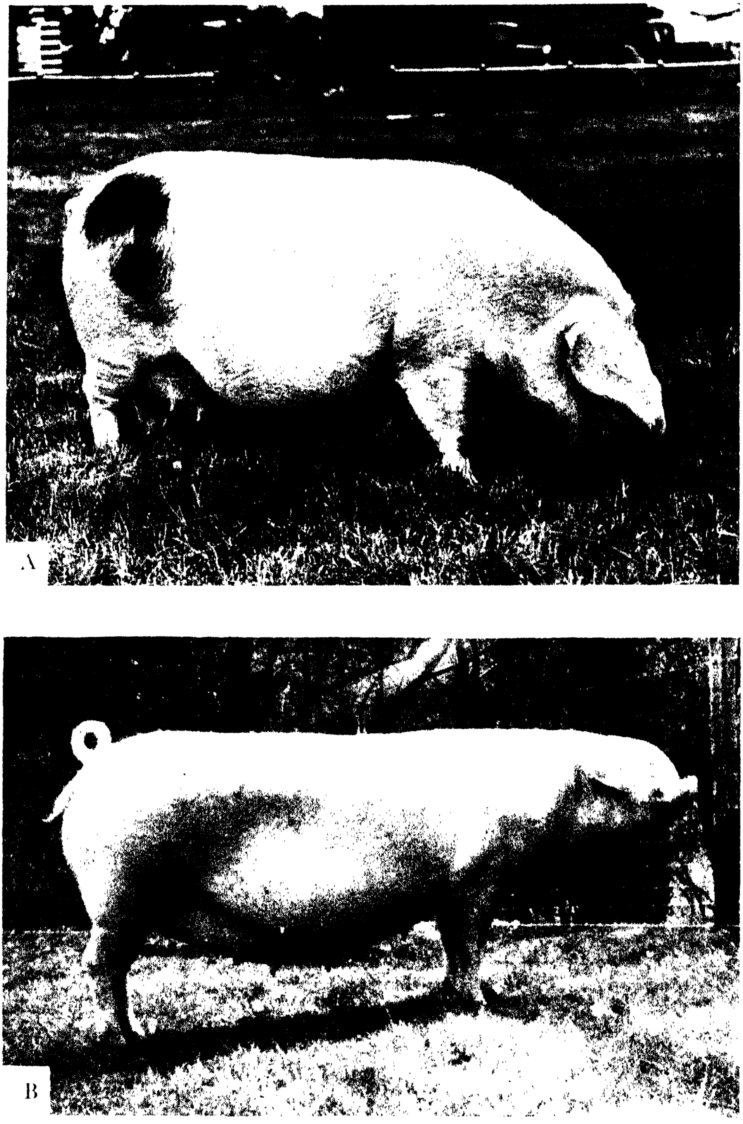


PLATE LV

A. Gloucester Old Spot Sow

B. Landrace Sow

products of the arable farms, viz. potatoes and tailcorn ; (*b*) with cheese-making areas where again their main function is to utilise the by-product of the industry, viz. whey ; (*c*) with urban areas, notably London and Birmingham, where large supplies of swill are available normally and (*d*) with market gardening where produce which might otherwise be wasted is fed to pigs. It may be practised also as a single enterprise dependent entirely on purchased feeding-stuffs.

Just as the integration of pig keeping in the farm economy is varied, so is its extent. Pigs may be kept in small or large numbers; breeding only may be done ; fattening only may be practised ; or both breeding and fattening may be carried on on the same farm. Experience indicates that the latter combination maintained at regular numbers, is the sounder economically. Even these different systems do not exhaust the variety of pig keeping, for production may aim at one of the main enterprises, viz. pork, bacon or breeding stock, or at a combination of these enterprises.

Market Requirements. No matter whether the product be pork or bacon the same type of carcase conformation is required. Briefly, when related to the live animal this means as great a length as possible from the point of the shoulders to the root of the tail, good width across the loins, and deep, well-fleshed hams. The head, neck and shoulders should be as light as possible, but too much narrowness at the shoulders should be avoided as otherwise there would not be sufficient room for internal development.

The pork trade demands pigs within the following weight ranges :

LIVE-WEIGHT.	DEAD-WEIGHT.
120–148 lb.	80–100 lb.
148–175 lb.	100–120 lb.

There is a limited demand for the " London porker " with a dead weight of 60–80 lb., and also a demand for good quality pigs of 120–160 lb. dead weight for manufacturing purposes.

The greater part of the demand for bacon pigs is for pigs of 198–220 lb. live weight and 140–160 lb. dead weight. There is an additional demand for " heavy hogs " at live weights up to 260 lb. yielding a carcase of 200–220 lb. dead weight.

When the Advisory Committee on Development of Pig Production reported in 1955, they rejected the idea of one type of pig satisfying the varied demands of the market. None the less they considered that the pattern of breeding and production could be simplified and improved. Towards that end they recommended the use of a single type boar on three types of sows. The boar should be white in colour and of the "late maturing" (bacon) type. Where bacon production was the sole aim the sows should also be of that type; to meet the demand for light-weight pork of 80–100 lb. dead weight the sows should be of an " early maturing "(pork)type; to produce pigs reasonably suitable for the general pork market and the bacon market, the sows should be of a " medium maturing " type.

BREEDING

The commercial pig keeper may use pure-bred sows and boars of the same breed, or he may prefer to cross sows of intermediate type, e.g. Essex, Large Black, Wessex, with a white boar type. By crossing, a certain amount of so-called hybrid vigour may be obtained, but the main advantage lies in making use of sows with the recognised good breeding, suckling and rearing abilities of certain breeds. Under good management and with careful selection, however, it is possible for all breeds to produce and rear satisfactory litters.

Every care should be taken to purchase as good a boar as possible. A boar may not be used until he is licensed : this licence must be issued before he reaches the age of six months and the licence is a guarantee that he is of good breed type. It does not follow, however, that all boars are of equal merit.

With the development of National Pig Records, introduced in September, 1954, much fuller information is now available to assist in the selection of breeding animals. Participating herds have available the breeding history of sows (number of pigs born, number of pigs reared to 8 weeks old and the weight of pigs at eight weeks old) ; in some cases details are available of rate of growth and carcase quality of litters. Since 1957 progeny testing has been available on a national basis and the results from the testing stations together with those from National Pig Records place most valuable information on breeding ability in the hands of pig keepers.

In selecting breeding stock, regard should be had not only to conformation but also to the family history of the animals. Good level performance over a number of litters is desirable. A reasonable standard to aim at for breeding sows would be 9 pigs reared per litter (or 18 pigs reared per annum) to a weight of 35 lb. per pig at 8 weeks old. It should be possible for fattening pigs to reach a live weight of 200 lb. in 200 days from birth with a food conversion rate of 4 lb. or under for each 1 lb. live weight gain from weaning to slaughter.

A sow normally comes on heat a few days after weaning, and if not mated the period of heat recurs at approximately twenty-one day intervals. A gilt first comes on heat when five to six months old, but should not be mated until she has grown sufficiently and reached a live-weight of 240 lb. A boar should not be used until he has reached a similar weight and until he is one year old should be used only moderately.

The breeding cycle is made up approximately as follows : Period of gestation, 112 days ; Suckling period, 56 days ; Interval before mating, 5 days ; giving a total of 173 days. It is possible, therefore, for a sow to produce two litters per annum, but if this is to be achieved in practice it is necessary for the pigman to keep a watchful eye on the sows to ensure that they are mated at the first heat after weaning, and that, should they not hold to this mating, they are mated again at the next heat. A record should be kept of service dates.

It is not a good general policy to let the boar run with the sows until they are safely in-pig. Sows should be brought individually to the boar for service. Experience shows that best results follow a service given late in the heat period, approximately forty-eight hours after the first onset.

The number of pigs born in a litter varies widely, but the average is between ten and eleven. Losses between birth and weaning occur mainly in the first few days of the life of the pig, and reduce the number weaned per litter to an average of about eight. Mechanical aids such as farrowing rails or farrowing crates may reduce crushing, the provision of electric heaters may lessen the risk of chilling. In practice, however, it will be found that certain sows and certain strains of sows habitually rear good litters, and the surest way to obtain a satisfactory number of pigs reared per litter is to concentrate on these good sows and strains.

In selecting breeding animals, good level performances over a number of litters are preferable to spectacular performances in individual animals. All breeding animals should be equipped with twelve teats.

FEEDING

The cost of food is the largest single item in the cost of producing a pig. For this reason it is essential that the pig should receive the correct quantity of food and the correct balanced ration of individual foods for its class and weight. Not only should it be balanced in protein and carbohydrate but it should also supply enough mineral matter and vitamins.

The digestive system of the pig, unlike that of ruminants, cannot deal with large quantities of roughage, hence the pig has to be fed on foods with a low fibre content. There is, however, a wide choice of foods at the disposal of the pig keeper although the main sources of carbohydrates are cereals and cereal by-products. Animal proteins such as white fish meal, or vegetable proteins such as decorticated ground nut meal, normally are the main sources of protein. Animal proteins are the most expensive component in a ration. Since they supply vitamin B_{12} they are essential to sows in late pregnancy, to suckling sows and to young pigs in early life when other sources of B_{12} are absent or limited. At other stages protein requirements may be met mainly from vegetables sources. Whenever the proportion of white fish meal falls below 10 per cent, minerals should be added to the ration.

In practice it is usually desirable to have three types of rations based on the nutritional requirements of the pig according to its body weight.

(1) Sow and Weaner Meal.
(2) Fattening Meal.
(3) Pig Starter Meal or Creep Feed.

The pig starter meal, with a protein content of 18–20 per cent, is specially designed for piglets from two weeks of age to just after weaning at eight to nine weeks when they should reach about 40 lb. live weight. Thereafter the sow and weaner meal with a slightly lower protein content (16–17 per cent) is more suitable for use up to about eighteen weeks of age or around 120 lb. live weight. This ration, as its name implies, is also suitable for the breeding sow, both before farrowing and during suckling. Finally, the fattening meal is used to follow on from 120 lb. live weight to bacon weight (210 lb.). The protein level in this meal need be no higher than

12–13 per cent and can be wholly of vegetable origin. Examples of these rations are set out below.

TYPES OF PIG RATIONS*

	(1) *Sow & Weaner*	(2) *Fattening*	(3) *Starter*
Barley Meal	5½ cwt.	6½ cwt.	2 cwt.
Wheat Meal	2 ,,	3 ,,	1 ,,
Middlings	1 ,,	3 ,,	2 ,,
Flaked Maize	—	—	2 ,,
White Fish Meal	¾ ,,	—	1 ,,
Decort. Ground Nut or Soya Bean Meal	¾ ,,	½ ,,	1 ,,
Grass Meal	—	—	½ ,,
Dried Skim Milk	—	—	½ ,,
Minerals	21 lb.	21 lb.	28 lb.
Vitamin supplement (A and D_3)	5 lb.	—	10 lb.

* To make approximately 10 cwt. lots.

Only high-quality grass meal should be used, the protein content being at least 18 per cent. The mineral mixture may consist of 3 parts chalk (or limestone flour), and 1 part of common salt. Alternatively, a proprietary brand of mineral mixture may be used according to the manufacturer's recommendations. The vitamin supplement should contain 800 units of A and 220 units of D_3 per gramme, but here again proprietary brands may be used as instructed by the makers.

Many variations of these rations are possible depending on the availability and price of the individual foods. Up to 2 cwt. of finely ground oats may be used as a part replacement of middlings or barley meal. Flaked maize or maize meal may replace an equal weight of barley, but should not exceed 3 cwt. in ration (2) because of the possibility of producing soft fat in the carcase. Ground peas or beans may be used instead of groundnut or soya bean meal in all three rations, 1 cwt. peas or beans replacing ½ cwt. groundnut (or soya bean) and ½ cwt. of barley meal.

MANAGEMENT AND HOUSING

Management of Sows. Wherever possible, in-pig sows should be kept on pasture. Not only will they obtain nourishment from the grass, but the exercise which grazing out of doors provides will keep them in fit breeding condition. They should be run together in matched lots not exceeding twelve in number. If this is not done, sows in poor condition, the weaker sows, and the younger sows may not receive their fair share of the food and they will be subjected to a certain amount of bullying from the stronger animals. Individual feeding arrangements may sometimes be desirable. During the first month of pregnancy any condition lost from suckling a previous litter should be built up and the quantity of food fed (approximately 6–7 lb. per day) should be adjusted to her needs. After this has been achieved she may be kept going on a moderate allowance (approximately 4 lb. per day) until the last month of pregnancy. During the last month the ration should be increased gradually to about 8 lb. per day just at farrowing. Any ringing of the sows that may need to be done should be carried out in the first weeks of pregnancy.

The sow should be put into the farrowing pen about seven days before she is due to farrow. Whenever soil and climatic conditions permit, farrowing is best done in huts out-of-doors, preferably on a portable fold system. The farrowing hut or pen should be cleaned out thoroughly before the sow enters it, and a supply of fresh clean wheat straw should be provided with which to make her bed.

Normally, there is no need for the pigman to be in attendance when farrowing takes place, but where sows are known to be careless or where a gilt is having her first litter, it is as well for him to be at hand. Attention should be given only when required and then unobtrusively. A few hours after farrowing the sow should be given the opportunity of drinking a thin gruel made with bran and then should go on to her normal ration. Care should be taken to see that the little pigs are suckling properly, and if it is seen that the sow is irritated during suckling, the sharp black teeth in the little pigs' mouths should be broken off with pincers.

As the litter grows the quantity of food fed to the sow should be increased steadily, the aim being to enable the sow to maintain condition without putting on flesh. Regard must be had also to the size of the litter ; the judgment of the pigman is all important. As a guide the maximum quantity likely to be necessary is 14 lb. per day.

When the litter is three weeks old, the little pigs should be offered some food in a small trough to which the sow cannot get access, i.e. a " creep ". Where separated milk is available this, with the addition of some middlings and later also barley meal and flaked maize, forms an ideal creep-feed. Where milk is not available, dry food should be given. The troughs should be kept clean and any unconsumed food should be removed daily. There is no doubt that creep-feeding enables pigs to be weaned in better condition and at heavier weights than when it is not practised. It also minimises the post-weaning check because the pigs have become accustomed to eating meals prior to weaning.

At six weeks old, male pigs not required for breeding purposes should be castrated, and even in really good herds only the very best young boars should be retained. At this age any tattooing or ear-marking should be done also. Some breeders prefer to castrate the male pigs when three weeks old. Weaning is usually abrupt, and it is a good plan to remove the sow and leave the litter for a week or so in the quarters to which they have become accustomed. The quantity of food allowed to the sow should be reduced in the last few days prior to weaning. The sow should be mated at the first heat after weaning unless she is being discarded from the herd or unless there is a special reason such as the necessity for farrowing on or near a specific date.

In recent years a great deal of interest has been taken in the development of an early weaning technique whereby it is possible to remove the little pigs from the sow soon after birth or at some later date between ten and twenty-one days old. Such a practice should enable a larger number of pigs to be born per sow per year since the time between litters is reduced. Early weaning is being practised successfully, but for this it is essential that the standard of management and of hygiene should be superior.

Management of Fattening Pigs. After weaning, pigs intended for fattening should be grouped into matched lots. For this reason it is advantageous to have two or more sows farrowing at the same time. Matched lots of pigs always thrive better than when the weight and condition are irregular. They should be confined in fattening pens or in yards. The number of pigs which may be housed together is determined by the trough space available ; approximately 13 in. of trough space should be allowed where it is intended to feed pigs to bacon weight, but 10–11 in. are sufficient where pigs are being fed to pork weight.

When nine to ten weeks old the pigs should be dosed to remove any worms with which they may be infested. A mixture of oil of chenopodium 5 per cent and castor oil 95 per cent will give good results. The mixture can be purchased ready for use from a veterinary chemist ; the instructions on the container should be followed accurately.

Pigs should be fed according to live-weight. Normal practice is to feed twice daily, but where conditions permit, good results follow three meals daily till the pigs are 100 lb. live-weight. Only an amount that the pigs will clear up in about fifteen minutes should be given ; over-feeding is one of the commonest causes of digestive troubles. The food may be fed mixed with water or dry with water added to the meal immediately after it is put in the trough. The proportion of water to dry meal should be approximately 2 : 1 by weight. The advantage of feeding the meal dry with added water is that each pen of pigs can be given the correct quantity of meal. Troughs and utensils should be maintained in clean condition.

Some farmers have had excellent results with *ad lib.* feeding from dry feeders. This practice can be commended until the pigs reach about 100 lb. live weight. After that controlled rationing is desirable in the interest of quality carcases.

Fattening pigs should be weighed at regular intervals to check progress and rationing. Where this is difficult, a representative pig from each pen should be weighed. Ideally, weighing should be weekly, but fortnightly weighings may prove sufficient. Any pig not making satisfactory progress should be sold as soon as it reaches a marketable weight ; in the earliest stages of fattening any bad-doer is best killed, and the first loss is then the only loss.

Fattening pens should be cleaned out daily and any soiled litter should be removed. In yards sufficient straw should be added from time to time to keep the pigs clean and dry.

Management of Breeding Stock. Young breeding stock should be kept out of doors on fresh pasture for as long as possible, but it is essential that they be kept in good growing condition and not allowed to receive any check. When housed they should be put into yards for preference, as yards give them more opportunity for exercise than do small pens. As with fattening pigs, too many should not be run together. Young boars should be kept separately from young gilts from at least four months old and preferably earlier. Where it is necessary to house young breeding stock they should be turned out regularly for exercise. Only animals of good quality should be retained for breeding. At weaning they should be culled severely, again when they reach pork weight and yet again at bacon weight. Only by so doing is it possible to maintain and improve breed standards. The highest possible standard should be set for young boars and they should be culled more thoroughly than young gilts.

Stock boars should be kept in fit condition and they should be fed according to their condition and the work that they have to do. Exercise is essential to the maintenance of fitness, and to ensure this a boar may be allowed to run with sows that are safely in-pig. At all times the boar should be handled carefully and firmly. When tusks have developed these should be cut back to remove a source of danger to the attendant.

Housing. Pigs are housed under a wide variety of conditions and in many types of buildings. Such buildings may be erected specifically for pigs, but there are many examples of the successful adaptation of buildings used originally for other purposes.

Methods of housing the pig have already been described in Chapter III.

Chapter XXIII

POULTRY

The poultry industry has changed greatly during the last decade. Prior to 1940 most poultry flocks were kept on general farms as profitable converters of home-grown grains, and not the least of their benefits to the farm was the improvement of grassland which resulted from their foraging activities, and the increased fertility from their droppings. Today the term " farm poultry " hardly applies, for even relatively small flocks on general farms are dependent on bought-in feeding stuffs and are looked on as a separate enterprise rather than as a part of a farming system.

The overall size of the poultry industry has increased greatly, as can be illustrated by the fact that in 1959 there were 35 million adult fowls in England and Wales, compared with 23 million in 1939. On the table poultry side of the industry an even more striking growth has occurred. In 1960 for instance, the production of broiler chickens, an industry which did not exist as short a time ago as 1950, exceeded 100 millions.

The size of individual farm flocks has increased ; in 1939 less than 18 per cent of adult layers in England and Wales were kept in flocks of over 500 birds, whereas in 1957 this figure had risen to 28 per cent, and the trend is still accelerating.

There has also been a marked change in the methods of keeping poultry. In 1939 less than 10 per cent of all poultry were kept wholly indoors, but in 1959 over 70 per cent of laying hens, and nearly all table poultry, were housed under some form of intensive system.

Commercial poultry keeping can be classified into two main branches, egg production and table poultry production.

EGG PRODUCTION

The production of eggs for the table has four basic requirements :

(1) Genetically fecund stock, which has been soundly reared.
(2) Warm, dry, adequately ventilated housing for the laying birds.
(3) A balanced diet which will sustain body weight and egg production.
(4) An adequate lighting pattern, either natural or artificial, or a combination of both.

The Breeding of Laying Stock. The breeding of commercial laying stock is a highly specialised and skilled occupation, and it is beyond the scope of this chapter to deal more than briefly with it. During the past fifty years poultry breeding has progressed from the mating of birds at random and selection of suitable stock by appearance and handling, to pedigreeing and progeny testing, and in recent years to the production of " in-crosses " involving the close in-breeding of blood lines, the crossing of these, and the testing of the progeny for egg production and other economic factors (see Chapter XVI).

The complexity and scale of modern breeding programmes, with their need in some cases for trained geneticists, and electronic computors, means that only large organisations with adequate capital resources can afford to carry them out. The result is that the poultry breeding industry is being concentrated into fewer but larger concerns, and the continuation of this trend seems inevitable.

Poultry breeding can be classified into three sections : parent stock breeding and progeny testing ; the production of hatching eggs for commercial laying stock ; and the hatching of these.

Parent Stock Breeding. This can be described as the selection and propagation of basic strains by means of trap-nesting, pedigreeing and progeny testing. These strains are usually in-bred to a varying degree, and selection is for many points, chiefly egg production and size, health and resistance to disease, food conversion rates, non-broodiness, hatchability, and other economic factors.

Selected stock of this type can be used directly for the production of commercial egg production chicks or, as is tending to happen, it can be further tested for its ability to " nick " with other strains, and so produce more profitable commercial laying stock.

Parent stock breeding and progeny testing are carried out by the type of large breeding concerns mentioned, and also by many smaller-scale independent breeders whose stocks have been built up by years of patient work and acquisition of knowledge.

The Production of Commercial Hatching Eggs. Tested pedigree stock is limited in numbers and cannot therefore supply the vast laying stock market. Instead, it is mostly used as parent stock for the production of commercial laying pullets. This operation may be carried out by the pedigree breeder himself, or by a commercial breeder or hatchery who purchases the parent stock.

In the case of the large breeding concerns, they usually farm out the parent stock to co-operating general farmers, and buy back the hatching eggs at an agreed price. A hatchery supply flock can prove a profitable adjunct on a general farm.

Hatching. Hen eggs take twenty-one days to hatch, and almost all commercial hatching is now carried out in electric cabinet incubators, which vary in size from machines taking only a few hundred eggs to those capable of hatching hundreds of thousands.

During incubation the eggs are normally candled once or twice with a strong electric light bulb and infertiles and dead germs are removed. The newly hatched chicks are sexed by highly skilled chick sexers, the cockerels usually being slaughtered and the pullets despatched to commercial egg producers.

Strict hygiene is essential in commercial hatching operations.

COMMERCIAL EGG PRODUCTION

The former yardstick by which a producer measured success in egg production, that of profit per bird, is being superseded to some extent by the business approach which thinks in terms of return on invested capital. Thus some of the larger egg producers are satisfied with perhaps lower profits per bird, but rely on larger total profits by increasing the size of their flocks.

Nevertheless it is still desirable to obtain the maximum profit per bird, and a knowledge of basic costs and returns is essential.

Costs. The percentage costs are roughly as follows :

Point of lay pullet (Home reared)	20–30 per cent
Food	60–70 per cent
Labour	5–10 per cent
Overheads, Depreciation, etc.	5– 7 per cent

It follows from these figures that major attempts at cost reduction should be directed at food saving. This can be achieved by the adoption of laying strains with high food conversion rates, by the elimination of all food wastage, and by a reduction in the cost per ton of feeding stuffs by home mixing, bulk buying and so on.

Returns. The major income obviously comes from egg receipts, and will vary according to the number of eggs produced and the price received for them. The price paid for eggs by the packing stations varies according to size and season. In the autumn many pullet flocks are only commencing laying and there is usually a relative shortage of larger-sized eggs. Prices for these grades, therefore, are considerably higher at this time of the year than in the spring and early summer. In general it can be said that maximum profits depend on a relatively high production rate of large-sized eggs during the autumn ; this can be achieved by purchasing the day-old pullets in the autumn or early spring, and by good management of the layers, including the judicious use of artificial light.

A high annual egg output per bird is also essential, and hen housed averages of over 200 eggs per bird should be aimed at. It is significant that University costings of egg production flocks usually reveal that the highest profits are obtained by those producers who achieve the best hen housed averages.

The only other income obtained by the egg producer is that of the price of the bird when sold for the table at the end of its laying cycle. This, however, is largely incidental and should not determine a producer's choice of stock or his feeding programme.

Hens *v.* Pullets. Laying stock will normally lay for about a year and then moult. During the moulting period, which lasts from six to ten weeks, the birds will cease production, and if kept for a further season will lay an average of 25–35 per cent fewer eggs than in the pullet year. In some cases the best layers are worth retaining for this second year, since the rearing costs will then be defrayed over two years instead of one.

Usually the high capital costs of housing make it imperative that the maximum profit per house should be made, and thus all-pullet flocks are more common.

Another argument against the retention of birds for a second year, is that the period of moulting coincides with the period of high egg prices.

Records. The keeping of a minimum number of adequate records is essential if maximum profits are to be made. These should comprise records of daily egg production and feed consumption, mortality and culls, weekly egg prices and packing station returns.

OBTAINING STOCK

Potential egg-producing stock can either be purchased as day-old sexed pullets, as growing stock, or as point-of-lay pullets. Most farmers purchase their stock at day-old for rearing on their own farms, and the rearing and laying stages are usually considered as one financial cycle. Specialist rearing farms catering for the growing demand for partly-reared and point-of-lay pullets are increasing in number.

The egg producer has a wide choice of stock, ranging from the traditional pure breeds and crossbreds to the so-called " hybrids " and crossed " in-breds " marketed under various proprietary names and numbers.

Generally, egg laying stock comes into five categories :

Heavy Breeds. These have a mature body weight of from 6 to 8 lb., and mostly lay brown-tinted eggs. The most common breeds are the Rhode Island Red and the Light Sussex.

Light Breeds. These have a smaller body weight—about 4–6 lb. when mature and lay white eggs. Common examples are the White, Brown, and Black Leghorn and the Ancona.

Heavy/heavy Crosses. Usually Rhode Island Reds crossed with Light Sussex.

Light/heavy Crosses. In recent years these have been the most popular stock for egg production. They lay slightly tinted eggs, and body weights are intermediate between the heavy and light breeds. Light/heavy crosses are usually Leghorns crossed with Rhode Island Reds or Light Sussex.

Stock marketed under trade names. The make-up of this stock is rarely disclosed, but mostly it is a product of crossed in-bred strains. These strains may, or may not, be pure breeds, and the commercial chicks may be two, three, or four-way crosses.

Most of the stock in this classification is based on the White Leghorn and is characterised by a smaller body weight than that of conventional stock—3½ to 4½ lb. being common.

Choosing Egg-laying Stocks. It cannot be emphasised too strongly that it is the strain that counts rather than the breed or title, and the stock should have been bred to live and lay well under average farm conditions. Other factors such as the size of egg and the body size of the hen also play a part in determining profits and the recent tendency by breeders to reduce body size arises from the fact that the bigger the bird the more food it needs to maintain body weight.

In the past a producer's choice of stock has been influenced by many factors ; the reputation of a breeder's stock in the district, past performance on the producer's own farm, the effectiveness of a breeder's advertising efforts, or the performance of his stock in public laying trials. Fashions in breeds and crosses have also changed from time to time, often for no apparent reason.

There is a wide variation in the quality of stock sold by different breeders and hatcheries, and until recently there was no practical yardstick by which a producer could judge a particular strain, other than that of actually trying it out on his own farm. Public laying trials can give an indication of a breeder's potential, but these are mainly of value in assessing the performance of breeding stock. The commercial layers which are mass produced for sale to commercial egg producers are not tested. Today many breeders and hatcheries are endeavouring to test the commercial egg-producing strains before putting them on the market.

Random Sample Tests. These independent tests of commercial laying stock have given the producer a means of discovering the potentialities of a strain before he buys it. A random sample is taken of the actual pullet chicks a breeder or hatchery is selling to commercial egg producers. This is then reared at the testing station, and kept for a year's laying. Results are published and are based on the actual profit or loss left by the pen of birds. This is assessed by subtracting the cost of the food eaten by the birds during the rearing and laying stages, from the value of the eggs produced as given by the egg packing station returns, plus the carcase value of the birds at the end of the year.

REARING LAYING STOCK

Laying stock takes from four to seven months to reach maturity and commence laying, depending on the breed, cross or strain. Smaller birds normally mature quicker than larger ones and the season in which the chicks are hatched also influences their rate of maturity. Chicks hatched in December and January may mature three to four weeks quicker than their sisters hatched in June. This is because they are being reared during a period of lengthening days, which has the effect of stimulating the glands controlling sexual maturity. Some producers aim at slowing down the rate of maturity of their stock by rearing it in windowless houses and restricting the amount of light given.

The rearing period can be sub-divided into two stages : brooding to six or eight weeks of age and growing to point-of-lay.

Pullets can be run in indoor or outdoor units for the whole of the rearing period, or a combination of the two methods can be adopted, indoor rearing for one stage and outdoor for another. The most common procedure is for chicks to be brooded completely indoors, but transferred to grass range units afterwards. Another popular method involves the use of haybox fold-units, which have no form of artificial heat but rely on conserving the body heat of the birds. Chicks are put into these units at three to four weeks of age, and transferred to other housing at about eight or nine weeks.

Chicks reared indoors can either be run on solid floors with litter, or on wire or slatted floors. A combination of the two methods is often adopted.

The Brooding Stage. Young chickens require warmth, food and water, and a supply of fresh air. They can be brooded in large or small units. Generally, the larger the unit, the less labour is required but the greater the degree of skilled management necessary. Where large numbers of young chickens are brooded together more bullying is likely and the proportion of culls may be higher than with smaller units. Great attention must be paid to points like adequate trough space and the removal of unthrifty birds in large units.

The Brooder. The source of warmth for the young chick comes in nature from the broody hen. In commercial chick rearing it is derived from some form of artificial heating appliance, of which there are many types. The most common fuels are electricity, propane or butane " bottled " gas and paraffin, and the heat can be either of a radiant or an infra-red type. The heat source can be situated above or below the chicks, or the whole environment of the brooder can be heated. Most brooders are designed to emulate the hen, and consist of a low canopy into which is incorporated some form of heating element. A type of brooder which very closely resembles the mode of action of the hen is one which relies on the actual contact of the chickens' backs with a warm electrically heated canopy.

The greatest amount of heat is needed by the chickens in the days immediately after hatching. As they grow, the down which covers their bodies will be replaced by feathers, and once a bird is fully feathered it has the ability to conserve its own body heat, and so keep itself warm.

A starting temperature of 95° F. is recommended for the brooder, reducing by 5° F. per week. The thermometer should be suspended so that the bulb is situated about two inches above floor level. However, whilst a thermometer is useful in assessing the temperature of the brooder to start with, once the chicks arrive it is better to disregard it and rely on their behaviour. If the chicks are too cold they will huddle in the centre of the brooder, and cheep plaintively : if they are too hot they will again cheep, but push themselves as far away as possible from the source of heat. When the temperature is satisfactory, the chicks will be spread evenly under the brooder and will nestle down in the litter.

In spite of the apparent artificiality of modern brooding systems, the attendant would be well advised to remember that the natural " rearer " is the hen, and that the behaviour of chicks under a brooder is closely related to their behaviour under a broody hen. They alternate periods of feeding and drinking in the exterior environment with periods of resting and sleeping under the warm brooder. The biggest danger of losses and of checks to growth occurs in the first fortnight and is caused by chilling. To eliminate this risk steps should be taken to : (1) Litter-down the brooding area and switch on the brooder, at least three days before the chicks are due to arrive. (2) Check the house for draughts and eliminate these. (3) Unpack the chicks straight from the delivery box to the brooder. Never unpack them in a cold atmosphere. (4) Restrict the chicks for the first few days to a very limited area around the brooder, by means of a hardboard or metal surround. This area can be gradually extended as the chicks become able to find their way to and from the brooder. (5) Ensure that the temperature of the area outside the brooder, where the food and water troughs are situated, does not drop below 55° F. during the first fortnight.

Chilling in the first fortnight of the chick's life can be responsible for more financial loss to poultry farmers than any other single cause.

Apart from the actual deaths caused by severe chilling, chicks only slightly chilled may become retarded, and their growth rate and performance later in life can be adversely affected.

Where chicks are floor-brooded the litter should always be kept dry. Peat moss, or a mixture of sawdust and chaff, make excellent litter materials for young chicks : a depth of about two inches is desirable.

Feeding. The feeding of chicks is a relatively simple task in these days of balanced complete diets. The common method is to give the chicks mash or granules *ad lib.* For the first few days the food should be scattered on coloured pieces of paper or cardboard so as to attract the chicks and get them eating quickly. It is also vital that the young chicks have plenty of light to see to eat.

Where continuous feeding is practised in flat troughs it is important to see that the mash or granules do not become stale. When re-filling the troughs, therefore, the attendant should tip any remaining mash to one end, and also he should try to keep an edge on the birds' appetites by compelling them to clean-up completely about twice a week.

Small amounts of kibbled grains can be fed from an early age if the rearer wishes. Until the birds are about a month old the amount should be limited to a mere handful per 100 chicks, particularly if they are housed indoors and have no chance to supplement their diet with insects, grass, or other vitamin-rich foods. After this age the amount can be gradually increased.

About twice a week, small amounts of fine flint or granite grit should be scattered on top of the food trough or in the litter.

Water should be available for chicks at all times, in shallow vessels which can be easily cleaned.

Disease Control. The chief disease hazards during the brooding stage are chilling, Salmonella diseases such as Bacillary White Diarrhœa, and coccidiosis. With all diseases the emphasis should be on prevention rather than cure. Chilling can be prevented by careful management of the young chickens ; the chances of getting an outbreak of Salmonella disease will be reduced if only chicks from blood-tested breeding flocks are purchased. (All accredited breeding flocks in the Poultry Stock Improvement Plan are blood-tested by the Ministry of Agriculture.) Coccidiosis can be largely prevented by ensuring that the litter is kept dry, and by maintaining a reasonable standard of hygiene.

The inclusion of drugs at preventative levels in the food and water against coccidiosis and other diseases is now common. It may be better and cheaper, however, to rely on a high standard of hygiene and good management and to keep the drugs in reserve for use at curative levels in case of an actual disease outbreak.

All rearing houses and equipment should be cleaned and disinfected between batches of chickens, and it is also advisable to " rest " equipment which has been in continuous use for long periods, so as to reduce the possibility of a disease build-up. A minimum of one month's rest per year should be aimed at.

Whilst a reasonable standard of hygiene and cleanliness is desirable at all times, it can be unwise to rear young chicks in conditions which are too aseptically clean, particularly if this standard cannot be maintained. There is a danger that chicks which have been reared in a clinically sterile environment may be more prone to troubles later on, when they come up against more normal farm conditions. A gradual building-up of immunity should be aimed at, and extremes of both cleanliness and filth avoided.

The Growing Stage. Chickens should be encouraged to feather quickly by a gradual reduction in the amount of heat. Soon it will be plain that heat can be dispensed with altogether and the rearer is faced with four alternative forms of housing the growing birds : small portable range houses ; fold units ; fixed wire-floored outdoor units ; or indoor flock houses.

Portable Range Houses. These are normally termed *Night-arks* or range-shelters, and usually accommodate from 50–100 eight-week-old pullets (Plate LVIA). They have slatted or wire floors and are used by the birds for sleeping in at night only ; during the day the chickens will be foraging and feeding outside. Good grass range is desirable, and the rate of stocking should not usually exceed 300–500 birds per acre, depending on the type of soil, and the period of use. The sleeping units must be moved regularly, at least once a week.

Fold Units. Instead of being given the freedom to roam at will on range, the chickens can be confined to mobile fold-units. There are various types in use, some being designed for hand-moving, whilst others require a tractor. Basically they consist of an enclosed sleeping section and a wire netting-topped run. As the ground enclosed by the run soon gets fouled, fold-units should be moved daily. A 10 ft. by 4 ft. fold unit will accommodate 30–40 eight-week-old pullets.

Fixed Outdoor Units. These are usually situated on brick pillars or wooden legs and have wire or slatted floors. They are similar in design to fold units and have an enclosed sleeping section and an open-topped run (Plate LVIB). One square foot per bird should be allowed at twelve weeks of age.

Indoor Flock Houses. Growing stock can be reared wholly indoors, either on litter or on wire or slats. Expensive, elaborate buildings are not necessary and pole-barn type structures, with cheap roofs supported on rough poles, and with open sides, can be satisfactory. If a producer wishes to delay maturity by light-control, however, then the rearing houses must be of more expensive types.

THE MANAGEMENT OF GROWING STOCK

This will vary somewhat according to the system of rearing, but there are some basic rules. All stock dislike sudden changes of environment, and the number of housing changes imposed on growing pullets should be kept at a minimum. The ideal is one house from day-old to point-of-lay. Every time a chicken is moved, say from brooder house to night ark, it receives a check in its growth rate, and during the days immediately following the move is more susceptible to disease. All unavoidable management changes, whether of housing, food or equipment, should be carried out as gradually as possible. Chickens are creatures of instinct rather than reason, and sudden changes of any sort are likely to bewilder them and lead to troubles. When birds are moved to night arks, for instance, they should be confined to the new units for the first twelve hours, and then to a temporary attached run for the next two or three days. After this they can be allowed to forage the range at will, and can be relied on to find their own way back to their sleeping unit. During cold weather it is essential to " cushion " a move to night-arks by placing straw or hay on top of the slats for the first few nights, or by placing a storm-lantern in each unit.

Where birds are being grown-on in indoor flock houses, they must be gradually weaned off the brooder and be accustomed to perch. The placing of low perches alongside the brooders when the chickens are about six weeks old will encourage this and in no circumstances should the brooder be removed until most of the chickens are perching, otherwise there is a danger of losses from smothering.

Where growers are being reared in small units on free range, these should be spaced out as far as possible from each other : the units should not be moved more than about 10 yards from their previous site at any one time so that the growers keep to their own house. The danger of some units becoming grossly over-crowded whilst others are nearly empty, which often occurs when large numbers of birds are being reared in one flock outside, can be further reduced if the attendant feeds the birds from different sides of the field each day. This is particularly important with grain feeding. If he starts at the same point each day, then gradually the birds will tend to drift towards this point, and the sleeping units there will soon become overcrowded.

Different age-groups should never be mixed as this leads to bullying and retarded growth among the younger birds.

Overcrowding must be avoided. A 5 ft. × 2 ft. 6 in. night ark will hold up to 50 or 60 eight-week-old pullets, but only about 25 mature ones. Similarly, 1 sq. ft. per bird can be allowed at eight weeks in solid-floor indoor rearing but the same birds will require about 3 sq. ft. by the time they are five months old. Overcrowding leads to uneven growth rates, a high percentage of culls, and disease.

Attempts should be made to prevent outbreaks of feather-pecking and cannibalism among growing pullets, by feeding the birds a " bulky " diet, and by reducing to a minimum the amount of light in the range houses or the indoor quarters. If there is just sufficient light for the attendant to see to do his chores, then the amount of light will be satisfactory for the birds. Range sleeping units should be blacked-out as completely as adequate ventilation will permit, because nothing is more likely to start an outbreak of cannibalism than having birds penned-up in brightly lit arks early in the morning before the attendant arrives.

Where birds are reared outside, predators, such as dogs and foxes, should be excluded by the provision of adequate fencing. Six feet-high wire netting, surrounded on the outside by a single strand of electric fencing wire about one foot high, will successfully deter most foxes.

The Feeding of Growing Stock. Growing pullets do not require such expensive rations as young chicks and whole-grain feeding can be recommended, particularly where the birds are on good grass range. Whole grains help to develop the intestinal organs, and to create an acid flora in the gut which can help to prevent such intestinal diseases as coccidiosis and fowl typhoid.

A simple feeding plan is to give the growing pullets the same type of mash or granules that they were getting as chickens, but to " dilute " it with more and more grain as the birds grow. On good grass range in the spring and early summer months pullets can be satisfactorily reared on all-grain, from ten to twelve weeks of age. On poorer quality range, the proportion can go as far as two-thirds grain, one-third chick rearing mash.

Where growing pullets have no access to outdoor grass runs, grain feeding should not exceed one-half of the total ration.

Growing pullets should have access at all times to clean water and to insoluble flint or granite grit.

HOUSING LAYING STOCK

There are five basic systems : hen batteries, deep-litter flock houses, covered yards, wire or slatted-floor flock houses, and outdoor units or range houses.

Hen Batteries. Laying cages can be constructed entirely of wire, or of wire and wooden framing. Most cages are about 18 in. high and 18 in. deep. The width of individual cages varies, depending on whether they are designed to hold one, two, or more birds, and the basic width for one heavy breed bird, or two light breeds is 14 in.

Cages are normally sited in blocks running the length or width of the houses, with 3 ft. wide gangways or service passageways between. Each block usually consists of three tiers of cages, two deep, situated back to back. Some producers have blocks of cages four tiers high, and use a mobile platform to enable them to attend to the top row.

The earliest makes of cages had individual food and water troughs and droppings trays, and made heavier demands on labour than other systems of keeping hens. This led cage manufacturers to concentrate their attentions on mechanising the system as much as possible. Thus most types of modern cages incorporate some form of mechanical feeding and cleaning-out system and all have automatic drinking troughs.

In recent years, the feeding system has become fairly standardised in the form of a continuous trough running the whole length of each block of cages, which is periodically filled by a moving hopper. This may be hand or mechanically operated (Plate LVIIA).

Drinkers are almost all of the same basic type—a continuous plastic or metal trough for each tier, which is regularly re-filled and flushed by a device known as a tippler-tank, or by a small tap at one end. Recently a new type of drinker has come on to the market —a nipple valve operated by the bird's beak.

Cleaning Systems can be classified under four main headings :

Scraper Cleaning. A hand or electrically operated " plough " moves over a metal or glass droppings tray. Cleaning must be done regularly, at least once a day, as the scrapers easily get choked up. The operation of the cleaning device can be geared to the food hopper.

Belt-cleaning. A plastic continuous moving belt, operated manually or by electric motor, carries the droppings to a collecting pan at the end of each block. Once-a-day cleaning is usually recommended. The chief drawback with this system is that the belts need renewing regularly, and are fairly expensive.

Paper-cleaning. This is a patented system whereby thin rolls of paper are situated on continuous moving belts of wire-netting. The droppings fall on to the paper, and are regularly removed manually or mechanically. The advantage of this method is that it is only necessary to clean-out twice, or even once a week. The main disadvantage is that the paper gets mixed with the droppings on the manure heap, although it rots down fairly quickly.

With scraper and belt cleaning, it is possible to have the droppings conveyed mechanically outside the battery-house. This is achieved by extending the trays or belts through an opening in the house wall.

Hand-cleaning. This old-fashioned method has been regaining popularity recently. Instead of individual droppings-trays to each cage as formerly, the modern version has a continuous droppings tray and the space between the bottom of the cage and this tray is such as to allow once-a-week cleaning. The system is claimed to be no more time-consuming than mechanical cleaning, and there are no parts to wear out or break down.

Deep Litter. The principle of deep-litter is the same as that of garden compost ; active bacteria are encouraged to " work " the litter, and convert the moisture from the droppings into vapour. This requires two essentials in the house, warmth and ventilation. Sufficient warmth can usually be achieved in the British climate by proper insulation of the house, and particularly the roof, which should also be as low as possible.

Ventilation is by means of baffled inlets situated just below eaves level, and outlets at the ridge. These can take the form of a 2 in. open ridge, with a flat ridge-board situated about 2 in. above it, or of ventilation chimneys. In houses of over 1500 sq. ft., electric extractor fans are usually necessary (Plate LVIIB).

A good depth of litter is essential. About 9 in. should be put down before the birds arrive, and this should be built-up to about 1 ft. later. The litter can consist of almost any dry, clean, waste vegetable matter of small particle size, such as wood shavings, sawdust, chaff, chopped straw, peat moss, or even cottonseed husks. Whole straw is inadvisable owing to its tendency to mat and break down very slowly.

The floor of the house can be of wood, concrete, earth, or well-rammed clinker and gravel. Concrete is safer as it can always be properly disinfected if an outbreak of disease should occur.

It is advisable to start the litter working before the colder autumn and winter months arrive. Litter which has not begun to heat-up before then is unlikely to start working afterwards unless the house is extremely well insulated. Correctly functioning deep litter should not need turning with a fork more than once a week, and the addition of lime is not necessary.

It is preferable to renew the litter each year. Apart from the possibility of a disease build-up from old litter, it is a valuable fertiliser for use on the farm. Although the litter is variable in composition, a typical analysis is as follows (figures in brackets give the average analysis of fresh poultry droppings). N, 1·8 (2·0) per cent ; P_2O_5, 2·3 (1·5) per cent ; K_2O, 1·4 (0·6) per cent.

If the old litter is being used for another season it is advisable to remove any caked lumps, and then heap up the remainder so that it will heat and kill any disease organisms. The heap should be turned at least once to ensure that all the litter goes through the heating process. After re-spreading the old litter, about 2–3 in. of fresh material should be placed on top.

The provision of a centrally situated flat droppings pit in a deep litter house can be recommended. This should consist of a flat platform 2 ft. 6 in. high, with a slatted or wire mesh top. It will only need cleaning out annually, but should be composed of removable sections to facilitate this.

All water troughs and most food troughs should be placed on top of the droppings pit, which the birds will use as a roosting platform at night. Up to two-thirds of the house can be covered by the pit, although one-third, or 1 sq. ft. per bird is usual.

Covered Yards. Open straw yards are seldom satisfactory, but many poultry keepers achieve good results with hens in covered yards. These may be adapted bullock-yards, or specially constructed cheap buildings. Basically, the latter consist of a cheap roof, say corrugated iron sheeting or roofing felt sandwiched between two layers of wire netting, supported on rough poles. The sides are usually left partially open, or covered by transparent plastic sheeting in winter. It is an important principle of these houses, that no attempt is made to operate them as true deep-litter units. Instead the aim is to maintain dry conditions by excess ventilation during dry weather conditions, and by regular additions of fresh straw or other litter, particularly during cold humid spells.

Excellent results can be obtained in covered yards where an attempt is made to provide the hens with a warmer sleeping-annexe. These slatted sleeping quarters may be sectioned-off parts of the main yard with wooden or straw-packed netting sides, or separate small houses. Adequate ventilation is essential in these sleeping annexes.

Wire or Slatted-Floor Houses. The difficulties experienced by many producers with the deep-litter system, in particular the problems of wet litter in winter, and the rising cost of suitable litter materials due to the increased demand, has led to the development of the wire or slatted-floor intensive house (Plate LVIIIA). In some cases all the floor area is covered by wire or slats, but many producers leave a small area of litter, so that the birds can dust bath.

Wire or slatted houses have the added advantage that capital costs are reduced, since about twice as many birds can be housed in a given floor space as on deep-litter, at little extra cost.

The floor should be situated about 2 ft. 6 in. from ground level, and should be sectional to allow easy removal when the house needs cleaning-out. This should only need doing annually.

Wire of 3 in. × 1 in. mesh, 10 × 5 gauge, welded and ungalvanised should be used, with bearers at 18 in. centres. Slats should be 1 in. × 1¼ in. tapered to ¾ in., with the broad end uppermost.

Ad lib. feeding of dry mash is advisable in wire or slatted houses, in order to reduce the risk of vices among the birds. De-beaking is also considered essential by many producers.

Range Houses. Due to the difficulty of providing artificial lighting, laying birds are seldom housed on range today. Labour costs can also be high and the system can only be profitable if the feeding of the birds can be cheapened by including a much higher proportion of whole grain in the diet than would be fed to indoor stock. In some areas there is also a demand for eggs from free-range stock, and higher retail prices may be obtained by the farmer marketing his own eggs.

Range housing is of two basic types :

(1) Solid or slatted floor mobile field houses, which need moving by tractor weekly.
(2) Fold units, which need moving by hand daily.

Up to 1 sq. ft. per bird should be allowed in slatted floor houses, and 3 sq. ft. in solid floor ones. About 1 ft. per bird perch space should also be allowed. Fold-units are usually 10 ft. × 5 ft. in size and house up to 25 birds.

It is important that the grass should be kept short when birds are running on it. The stocking rate should not exceed 250 birds per acre.

A COMPARISON OF THE THREE MAIN INTENSIVE SYSTEMS OF EGG PRODUCTION

With all three systems, windowless houses may be used, otherwise 1 sq. ft. of side window space per 100 sq. ft. of floor space should be allowed.

Roof lights are not advisable due to the excessive heat loss which is likely to occur through them, but where they are unavoidable, 1 sq. ft. of roof-light space should be allowed per 24 sq. ft. floor space.

Artificial lighting should be provided with all types of houses, at the rate of 60 watts per 100 sq. ft.

Ventilation is particularly important in battery or wire floor houses, where heavy stocking rates are practised, and electric extractor fans are usually necessary. An extraction rate of 1½ cu. ft. of air per lb. body weight of the birds can be taken as a useful guide.

FEEDING LAYING STOCK

Ad lib. feeding of mash or pellets is preferable for laying birds kept indoors, although some rationing may be practised if the birds

TABLE 16

THREE INTENSIVE SYSTEMS OF EGG PRODUCTION COMPARED

	Deep Litter	Slats or Wire.	Cages
Height of House.	5 ft. to eaves. Ridge as low as possible, depending on width of house and pitch required.	Ideally 6 8 ft. to eaves 8 ft allows operator to stand. Lofty buildings not necessary but can be utilised.	2 or 3 tiered cages, 6 ft. to eaves level. Lofty buildings not desirable.
Floor.	Any dry floor including earth or gravel Concrete or wood can be disinfected	Earth or any dry floor Wire or slats must be 2 ft 6 in above floor level	Must be concrete or wood, vermin proof and damp proof.
Roof.	Insulation essential.	Insulation desirable	Insulation desirable.
Nest Boxes	Single nests situated in darkened laying room Sawdust or shavings make the best nest box litter	Difficulty is sometimes encountered with floor laying. Boxes best situated in darkened laying room or in corners of house	Clean eggs assured if cage floors and cradles kept clean.
Floor Space per Bird	2½ 3½ sq ft	1½ 2 sq. ft	1¼ 2 sq ft. depending on number per cage.
Cleaning	Annual or litter can be used again.	Annual. Slats or wire frames easily soaked in dip-tanks and cleaned Droppings can be dry and friable if floor is dry and ventilation good.	Scraper or belt cleaning—daily. Others—twice or once weekly. Droppings often wet and difficult to dispose of Annual cage clean with pressure hoses essential.
Labour Requirement.	Low if litter dry and working if wet, labour of egg cleaning can be heavy	Very low. One man to 10,000 birds is possible.	Fairly low if mechanised feeding and cleaning system used.
Vermin, flies etc	Rats and mice can be troublesome if floor not vermin proof	Poisons can be placed below slats and wire with safety. Flies can be troublesome, but spraying and use of electrical vapourisers effective	Floor and house should be vermin proof.
Replacements.	Birds cannot be added to existing pens		Empty cages can be filled up.
Culling.	Difficult because of risk of upsetting flock.		Easy to identify and catch culls.
Records.	Good production possible but not normally equal to results from cages if flocks of more than 500 birds are run together.		Individual bird or cage records are possible and high egg production rates can be achieved.

are becoming fat. Small type birds in full lay normally eat about 4 ounces of food per day ; heavy breeds will eat 6 ounces or more.

Mash is usually fed to flocks on deep litter, wire floors, and in multiple bird cages, as the birds take longer to consume it than pellets, and therefore it helps to reduce boredom. Pellet feeding is claimed to be less wasteful than mash although this is largely a question of trough design. Birds housed intensively may have to be de-beaked if pellet feeding is required.

Grain can be fed to laying birds, usually in the form of a scratch feed once a day. The amount should not exceed one ounce per bird, however, unless special grain balancer rations are fed, in which case whole grain can form as much as 50 per cent of the total diet.

Mixed grit in the proportion of four of limestone or oystershell to one of flint or granite should be scattered on top of the food troughs about twice a week. Alternatively the birds can be given grit in special grit hoppers or troughs.

Clean water is essential, and many types of automatic drinking troughs are on the market. Points to look for are that the troughs should be simple and foolproof in operation, easy to clean, and designed to prevent the birds from flicking too much water on to the litter.

Adequate trough space is important where large numbers of birds are housed in one unit. Even when *ad lib.* feeding is practised, shy birds will be unable to eat enough food for maximum egg production due to bullying on the part of their stronger flock mates, unless plenty of troughs are situated in all parts of the house.

Thirty feet of food trough and 3 ft. of water trough space per 100 birds are considered essential.

GENERAL MANAGEMENT OF LAYING BIRDS

If possible laying birds should be transferred to their permanent quarters at least two weeks before they begin to lay. A check such as is given by a move to new houses will stop production if it has already begun. When several hundred pullets are being transferred from range to one large intensive house, it is advisable to move them in several small batches of fifty or a hundred at a time, in order to avoid losses from smothering, which are likely to occur among large flocks in strange surroundings. It may also be necessary to pay an evening visit to the house for a few nights to see that the birds are roosting in the proper place, and not in the nest boxes or corners of the house.

Some strains of high producing laying stock are inclined to be of a nervous disposition, and small upsets, such as the dropping of a feed sack can create panic in a flock, and result in lowered egg production and premature moulting. It is therefore essential for the attendant to carry out all routine management chores as quietly as possible.

The regular handling of flocks and the removal of unproductive birds, which used to be common practice in the past, is no longer recommended, again due to the risk of upsetting the birds ; nevertheless sick birds should always be removed and disposed of quickly because of the risk of infection spreading.

Where it is essential to do some sort of culling of the flock, as for instance when production is very low, this should be carried out after dark with the aid of a torch, or a blue tinted electric light bulb. Often it is only necessary to go along the perches and feel the birds' crops. Any without food in them two hours after roosting time can be considered doubtful layers.

The Lighting of Laying Stock. Experience has shown that the intensity of light in laying houses is not of great importance. Provided that there is enough for the attendant to see adequately to do his chores, then it will be satisfactory for the birds.

The day-length received by the birds is of vital importance, and this fact has long been recognised by commercial egg producers. High egg production during autumn and winter depends on the supplementation of natural daylight by artificial light, and a 14–17 hour day has been considered the optimum. Automatic time switches are widely used to regulate the amount of electric light given.

Recent work carried out by Reading University and in the U.S.A. has indicated a new approach to the question of lighting. It has been shown that laying hens react better to an *increasing* day length rather than to a steady 14–17 hour one. Best results are obtained with the system when the light is controlled during both the rearing and laying stages, and the chief requirement is thus windowless housing for the stock.

Where this is available chicks should be given 22 hours light per day for the first two weeks. The light should then be progressively reduced by about 15 minutes per week until the birds begin laying. It should then be held at this level until the birds reach peak production, which usually will be at about 30 weeks of age. As soon as production has stopped rising, the light should be progressively increased by 15 minutes per week to a maximum of 20–22 hours per day.

By this system the maturity of the birds is delayed by two or three weeks, but they can be expected to reach maximum egg size quicker, to lay slightly larger eggs throughout the laying year, and in some cases to lay slightly more eggs, than stock reared and housed conventionally.

Modifications of the system are possible in houses with windows. The amount of natural daylight the birds are receiving when they come into lay should be maintained by artificial means until they reach peak production, after which it should be increased by 15 minutes per week to a maximum of 20–22 hours. Obviously there is less scope with the system when natural daylight is permitted.

Disease Control of Laying Stock. Strict hygiene is essential when large numbers of laying birds are housed together. Water troughs should be regularly cleaned, and food troughs should be designed to prevent the birds from fouling the contents.

A thorough cleansing and disinfecting of the laying house is desirable annually, before a new batch of birds is installed. Where possible, the floor, walls and equipment should be scrubbed with a solution made up of two cupped handfuls of ordinary washing soda to four gallons of hot water. Afterwards the house should be swilled out or sprayed with a general disinfectant. In addition all woodwork should be treated inside and out with a preservative. After this the house should be left empty for at least a fortnight to allow any fumes to clear away.

Adult poultry are prone to many disease conditions of which the main ones are Lymphomatosis (fowl paralysis), the Leucosis Complex (" going light "), Fowl Typhoid, Tuberculosis, Pullet disease, reproductive disorders such as prolapsus, and many respiratory diseases such as Fowl Pest (see p. 704).

In all cases where an outbreak of disease is suspected, expert advice should be called in, and if necessary specimens should be sent for post mortem examination.

Prevention is cheaper than cure, and apart from the hygienic measures suggested, it is also advisable to site laying houses as far away as possible from chicks and growing stock. Adult birds may be " carrying " many diseases which can affect young stock.

Marketing Eggs. Producers are free to market their own eggs in any way and at what price they like, but the majority sell to the British Egg Marketing Board through a registered packing station. At the present time eggs sold in this way receive a Government subsidy which is administered by the Board.

Packing Station prices for eggs are paid according to their size, and five grades normally (1961) apply :

Large	not less than $2\frac{3}{16}$ oz.
Standard	$1\frac{7}{8}$–$2\frac{3}{16}$ oz.
Medium	$1\frac{5}{8}$–$1\frac{7}{8}$ oz.
Small	$1\frac{1}{2}$–$1\frac{5}{8}$ oz.
Extra small	not more than $1\frac{1}{2}$ oz.

Deductions are also made for cracked and dirty eggs and those with internal or shell faults. It is in the producer's own interest therefore to ensure that his eggs are fresh and clean when marketed.

The design of the nest box has a big influence on the condition of the eggs when gathered. Basically a nest box should be dark, well ventilated and easily cleaned. Single cubicle boxes situated in darkened nesting rooms are ideal, provided they are designed to accommodate at least 4 in. of litter and that this is frequently renewed. Sawdust or shavings make the best nest box litter. One nesting compartment to five birds will be required.

Alternatively, sloping, wire-floored nest boxes, of which many types are available, can be used : these can be extremely efficient, although in some cases the birds have to be encouraged to use them by the placing of straw on top of the wire for the first few days. In these boxes the egg rolls away out of the bird's reach and cannot therefore be contaminated by droppings or dirt from the feathers.

Collections from the nest should be frequent, preferably at least three times daily, and more often during extremes of hot or cold weather. The collecting utensil should be of flexible construction and easily cleaned. Metal buckets are not suitable, and will increase the incidence of cracks.

Broodies. Hens wishing to brood eggs can be distinguished by the insistent clucking sound they make. They should be removed from the nest box immediately their condition is obvious, as apart from the fact that the longer they are allowed to remain, the longer they will be out of lay, broodies are also responsible for much egg breaking and soiling. They should be placed in a special wire or slatted cage, and fed and watered regularly. If removed quickly they should begin to lay again within a week.

Cockerels should not be allowed to run with hens intended for commercial egg production, otherwise there is a danger that embryonic development of fertile eggs will be started by broodies sitting on them.

Egg Storage. After collection, clean eggs should be packed in egg trays, and stored in a cool well-ventilated room until ready for despatch. Stained and dirty eggs should be cleaned, preferably by using a dry abrasive such as wire-wool, or alternatively with a clean damp cloth.

When many eggs require cleaning, this can be done mechanically. Several types of dry cleaning machine are on the market, although at the present time few of these are entirely satisfactory. Many types of egg washing machines are also available and are widely used by commercial egg producers. Egg washing can prove extremely deleterious to the keeping qualities of eggs : to minimise this effect, efforts should be made to keep the water reasonably clean and at a temperature of 80° F. because water at a temperature lower than that of the eggs tends to be absorbed through the shell. (It is also advisable to allow the eggs to dry on a wire-mesh tray afterwards, rather than to pack them straight into the egg boxes whilst still damp.)

TABLE POULTRY PRODUCTION

The production of birds for the table can be classified into five sections ; broilers, capons, turkeys, ducks and geese.

BROILER PRODUCTION

The term *broilers* is applied to chickens reared in large flocks under conditions conducive to fast growth and high food-conversion rates, and marketed at from eight to eleven weeks of age, at weights of from 3 to 4½ lb. Birds marketed even younger than this, at five to seven weeks old and weighing from 1 to 3 lb., are normally termed *poussin.*

Breeding Broiler Stock. Chicks suitable for broiler production must be plump and uniform, with white flesh and feathers. The birds must grow and feather rapidly and should be docile in nature. In the early days of the industry broiler growers had to rely on surplus cockerels from egg production strains. These were mostly Light Sussex crosses, the most common being Rhode Island Reds crossed with Light Sussex. This type of stock can give satisfactory performance but its quality is variable, and supply is entirely dependent on season. In the winter and early spring, for instance, when most egg producers obtain their day-old replacement pullets, surplus cockerels are plentiful and cheap, but during the summer and early autumn they are scarce and expensive. These factors have led to the development of specialised strains of broiler breeding stock, and there is little doubt that all broilers will be from stock of this type in the future.

Specialist broiler stock is derived from strains of the White Plymouth Rock, the White Cornish Game and the New Hampshire Red. The White Leghorn has also been introduced into some strains in order to fix the dominant white feather coloration.

The grower's demands for large numbers of chicks at one time, and for stock of uniform characteristics, has led to the concentration of broiler breeding and hatching into a few large commercial concerns. This trend is likely to continue. These breeding organisations carry out the development and testing of new strains of broiler parent stock on their own farms, but distribute the actual commercial breeding stock to co-operating farmers. The hatching eggs from these birds are then purchased by the organisation, which hatches them and sells the day-old chicks.

At the present time, in order to encourage good strains of broiler birds, random sample progeny tests are being carried out by the National Laying Test Limited, and the British Broiler Growers Association are also hoping to begin tests of this nature in the near future.

Broiler Production. The aim of the broiler grower is to purchase suitable stock and get this to marketable weight as quickly as possible. Large-scale operation is necessary, as profits are usually estimated in pence per bird rather than in shillings. At the present time twenty thousand birds per year in four batches is thought to be the minimum number worth considering, but it is possible that this scale of operation will soon be considered too small. As the supply of broilers on the market increases, so the price tends to drop, and the producer's profit level is further reduced.

The producer has little control over the price per pound that he receives for his birds, and profits can only be maintained or increased by obtaining higher weights and by a reduction in the costs of production. These costs are made up of the chick, food, labour, fuel and electricity, depreciation of buildings and equipment, interest on capital invested and miscellaneous items such as replacement of electric light bulbs and so on. Of these items, the two which amount to more than 80 per cent of total costs are the chick and the food. The chick price is largely out of the producer's control and it is on a reduction of food costs, which can amount to more than 60 per cent of the total, that attention is concentrated. The key factor is the food conversion rate of the birds, and much progress has been made in improving this in recent years. Figures of under 3 lb. of food per 1 lb. of meat are now commonplace.

Food conversion rates are influenced by many factors, including the age and size of the birds, the genetic capability of the stock, the temperature of the house and the food quality. Briefly, it can be said that the fastest growing birds give the best conversion rates, and that the younger the birds are when marketed the better. Also the quality of the food obviously influences its conversion rate, and the higher the energy content of a ration the more efficient it is. Price and other factors enter into this, however.

In an attempt to measure the efficiency of a food when birds of varying weights are produced, a figure known as the performance efficiency is used, thus :

$$\text{Performance Efficiency} = \frac{\text{Live weight} \times 100}{\text{Food conversion ratio}}.$$

The higher the figure the better, and Performance Efficiency figures of over 120 are now possible.

The table below summarises the chief items of costs of producing broilers.

TABLE 17

AVERAGE COSTS OF BROILER PRODUCTION

(*pence per lb. deadweight*) (*16 flocks in 1959*)

Item of Cost.	Average.	Per cent of total.
Chicks	5·1*d.*(1*s.* 3*d.*)	23
Food	12·8*d.*	58
Heating	0·6*d.*	3
Labour/Management	0·9*d.*	4
Other prime costs.	0·7*d.*	3
Depreciation on buildings and equipment	2·0*d.*	9
	22·1*d.*	100

Average deadweight	3·6 lb.
Average mortality	5 per cent
Average food conversion ratio	2·671
Average age at killing	72 days
Average grading	85 per cent Grade A

Housing. Since it is essential to produce broilers in very large numbers in one flock, a building of correct design is most necessary. Existing accommodation can be adapted, providing it has the following essential points :

1. Sufficient floor space—producers are at present working on the basis of 0·75 to 0·8 sq. ft. per bird, from day-old to nine, ten or eleven weeks when the birds are marketed.
2. As the building should be as nearly square as possible, most broiler houses are between 40 and 70 feet in width. The height of the ceiling should not be more than 8 ft. maximum. The shape of the house and the height of the ceiling are important factors in maintaining an even temperature.
3. The floor must be dry and level. Earth or well rammed clinker and gravel are often used, but concrete is better as it can be easily cleaned and disinfected.
4. If windows are to be installed they should be placed at eaves level, although where heavy stocking is carried out, experience indicates that it is best to dispense with windows altogether, and to provide artificial lighting (Plate LIXA). This allows a measure of control since it has been found that birds can be made to react quite differently to lights of various colours and lighting patterns.

5. The best temperature for broiler production is between 60° and 65° F. It is within this temperature range that food conversion is likely to be at its best, and the birds likely to be most contented. In order to maintain a constant temperature in the broiler house, proper insulation of the roof and walls is necessary. Glass wool plus an impervious lining has been found satisfactory, but many other types of insulation materials are on the market.
6. Ventilation is usually by means of baffled inlets at eaves level, and thermostatically controlled extractor fans in the roof. An extraction rate of 1½ cu. ft. of air per 1 lb. liveweight per minute is advisable and fan manufacturers' recommendations should be closely followed.

Equipment. Broiler houses must be thoroughly well equipped if good results are to be obtained.

Brooders. Hot-water pipe brooders fired by coal or oil are considered to be the most efficient form of heating for large houses. Propane or butane gas-heated canopy brooders are useful in smaller houses, and are preferable to infra-red type brooders for broiler production. Electrically-heated canopy brooders are suitable, although like infra-red brooders they tend to give a dry heat which can have a somewhat unfavourable effect on feathering. A type of permanent electric floor heating system is also gaining popularity.

Water Supply. A one-gallon baby chick fountain should be allowed per 100 chicks for the first few days but later the birds should have access to proper water troughs allowing 20 ft. in length per 1,000 birds.

Feeders. Uneven growth rate is one of the symptoms of shortage of feeding space. If mash is fed, a greater length of trough must be provided than that used in the feeding of crumbs. If dry mash is being fed throughout, the allowance of trough space per chick should be 1 in. at day-old increasing to 3 in. by eight weeks of age. Nowadays, hanging tubular type feeders are generally preferred in broiler houses, although these are more suitable for crumbs than for mash. Tubular feeders should be provided at the rate of 30 per 1,000 birds, which in a house 40 ft. wide allowing 0·75 sq. ft. floor space per bird means that the feeders would be situated in eight rows running down the house, each feeder being 5 ft. from its neighbour in the same row.

Lights. As mentioned earlier, there is an increasing tendency to dispense with windows and to use artificial light instead. A 40-watt bulb per 250 sq. ft. of floor space is probably ideal, although some producers favour as little as a 15-watt bulb for the same area. Brighter lights should be used for the first ten days or so, and may be reduced (by substituting lower wattage bulbs) by the time the birds are fourteen days of age. Red coloured lights appear to have a quietening effect on the birds, and have been found of great assistance in preventing and controlling outbreaks of cannibalism and feather pecking. It is important to ensure that the birds are never plunged into complete darkness, as this could result in panicking.

Litter. Wood shavings, sawdust, chopped straw and peat moss, either alone or preferably mixed, are all suitable for litter. Unless there is an outbreak of disease in a batch of broilers, it is not absolutely essential to remove the litter for each batch, although it is probably best to do so. However, if it is decided to rear a second batch on the same litter, all caked and damp patches should be removed and the remaining litter should be heaped. This should result in the generation of heat, which is said to kill off any parasites or disease in the litter. After the heating process has been allowed to continue for four–five days, the heaps should be broken down and the outside turned to the inside and the whole reheaped. After a further week the litter may be redistributed over the floor of the house.

Broiler litter is a useful fertiliser, and on average contains about 70 per cent dry matter, 2·3 per cent N, 2·0 per cent P_2O_5, and 2·4 per cent K_2O.

Feeding. Broilers must be fed *ad lib.*, i.e. they should always have clean fresh food in front of them. This is essential to obtain the rapid growth rate desirable. Crumbs or mash may be fed, although the majority of producers prefer crumbs, as mash does not always run smoothly in tube feeders. Crumb feeding may predispose the birds to feather pecking and cannibalism and thus a constant watch should be kept for an outbreak of these vices and extra care should be given to the lighting of the house. De-beaking of the birds may also be necessary at fourteen days of age.

Broiler rations tend to be higher priced than rations for egg-producing stock. This is due to the fact that the extremely intensive conditions under which broilers are kept, and the fast growth rates resulting, tend to reveal very quickly any deficiencies in the ration. Thus broiler rations are fortified with extra vitamins and minerals, and also have higher protein and energy content than equivalent amounts of other rations. Stabilised fat is added to some rations in order to increase the energy content. The inclusion of drugs and antibiotics at low levels to prevent certain diseases is also necessary.

Because broiler rations are more complex than other poultry rations, most producers prefer to buy-in ready mixed proprietary feeding stuffs, although a few mix their own, with a resultant saving in cost. Bulk delivery and storage of proprietary feeding stuffs is now common in broiler units, and mechanical feeding of the birds is a growing trend.

Diseases. The risk of serious losses from disease is reduced by the batch system of broiler production, i.e. where one lot of birds is placed in a house and run straight through until killing, after which the house is emptied, cleaned and disinfected ready for a subsequent batch. A rest period of ten to fourteen days between batches is advisable, since not only does this allow time for the thorough cleaning needed but it also reduces the risk of disease from sub-clinical infection. Poultry-houses, as well as land, can become " poultry sick " and thus at intervals it may be necessary to rest houses for longer periods than normal.

Even with strict hygiene and rest periods, however, the rearing of large numbers of chickens indoors in large houses would be impossible without the use of drugs at preventative levels in the food. All broiler rations, therefore, contain coccidiostats, antibiotics and other growth stimulation supplements.

It seems likely that the use of oral vaccines to prevent outbreaks of respiratory diseases and so on in broiler houses will increase in future years.

Marketing. Broilers are usually sold off the farm alive, in " crops " or batches, and the plucking and processing are carried out in large modern packing stations. Experience over the past three or four years has shown the broiler industry the danger of a producer entering broiler production without having first made comprehensive arrangements for the marketing of his birds. This is best done with a packing station of repute, but no packing station can carry on business until its supplies of broilers are regular and are uniform in type and grade. A steady, even flow of birds is what is required. Because of this requirement most broilers are now grown and marketed under the " group " system. Under this, a packing station is set up, either by an independent body, or by the producers themselves. Producers are given contracts to supply birds to the station, on set dates, and by this means the packing station can plan ahead to ensure a steady throughput.

The " group " system has distinct advantages from the packing and marketing angles, but producers have to sacrifice some of their independence. Not only are they instructed when to take and sell their birds, but also they may be under obligation to buy certain brands of chicks and foods.

CAPON PRODUCTION

Capons are cockerels which have been chemically or surgically caponised (i.e. emasculated). They are usually killed when sixteen to twenty weeks old, and weigh from 6–9 lb. They are seldom produced in large numbers, being mostly reared in small flocks on general farms. The chief markets for capons are at Christmas and Easter, although there is a steady but smaller demand throughout the year.

Surplus cockerels from egg producing strains are mostly used for capon production. White fleshed and white feathered birds of a large type are desirable, and the Light Sussex or the Light Sussex crossed with the Rhode Island Red are very suitable.

Elaborate houses are not essential for capons ; it is merely necessary to keep the birds warm and comfortable and ensure that they are not overcrowded. Mobile, solid or slatted floor field houses are often used, although capons may be reared in any old unused buildings, such as loose-boxes or hay lofts.

Expensive forcing diets are not necessary for capon production. Instead the birds are normally given ordinary rearing mash or crumbs for the first six weeks, after which time grain feeding is introduced. The quantity of grain can be gradually increased as the birds grow and, if they are running outdoors, it can comprise over 70 per cent of their total diet by the time the birds are twelve weeks old. Many capons on general farms exist for several weeks without any form of supplementary food, being run as scavenger flocks on stubble fields.

The *ad lib.* feeding of a broiler-type finishing diet for the last three or four weeks is advisable when capons have been reared on cheap and restricted diets.

Surgical caponising, which involves the removal of the testes through an incision in the bird's back, is rarely carried out today. Instead the cockerel is implanted with a synthetic female hormone in the form of a small pellet, or of paste. This is inserted just underneath the skin at the top of the neck, a site chosen because the hormone, which does not dissolve, will be thrown away with the head when the birds are eviscerated. Cockerels are normally caponised with one 15 milligram pellet of stilboestrol or hexoestrol at ten to twelve weeks of age, and again six weeks before killing, if necessary. The effect of the oestrogen usually wears off after about six weeks.

TURKEY PRODUCTION

There has been a very marked expansion in this section of the poultry industry within the last decade, and particularly since 1953 when turkey imports from certain countries were banned because of fowl pest. In 1959, nearly 2½ million turkeys were produced in England and Wales, which was nearly three times the 1952 total. Most turkeys are still sold on the Christmas market, although there is a slow but steady increase in demand at other times of the year, particularly at Easter.

Turkey Breeding. Turkey breeding stock is still kept mainly outdoors, often in fold units, but intensive breeding is a growing trend. The turkey industry is tending to form itself along the same lines as the broiler industry, and although most turkey breeding flocks are relatively small in size at the moment, several flocks are measured in tens of thousands.

Turkey stock is mostly either white or black in plumage colour and can be classified also in respect of size and conformation.

Size. Small type turkeys are those with a mature bodyweight of 10-12 lb. for females, and 14-16 lb. for males. In recent years small breeds of turkeys have lost popularity because of their poorer food converting ability. The chief breeds in this classification are the Beltsville White and the Norfolk Black.

Large type turkeys have mature bodyweights of 14-16 lb. for females and 20 lb. and upwards for males. The chief basic breeds are the American Mammoth Bronze and the Empire White.

Conformation. Most strains of commercial turkeys are now termed " broad breasted ", i.e. at twenty weeks of age they have a minimum breast width of 3½ in. at a depth of 1¾ in. at the widest part of the breast.

In recent years turkey breeders have tended to select for conformation, and particularly breast width, to the detriment of other economic factors, and troubles with poor fertility and hatchability and egg production have arisen.

Some strains of turkeys will lay 80-100 eggs in a laying season extending from February to September, but many of the broader-breasted strains lay only 40 or 50 eggs a season.

Artificial lighting patterns are being used by some breeders in an attempt to extend the laying season, and get a more even flow of eggs throughout the year.

Because of poor fertility, artificial insemination is widely used. Semen from stags cannot be diluted and stored as with bull semen, and must be used within one hour.

Turkey breeding flocks may be mated in single pens, one stag to 12–14 hens; or flock mated. The eggs are mostly hatched in electric cabinet incubators, and take twenty-eight days to hatch.

Rearing and Growing. Turkeys may be reared in large or small flocks, and a variety of housing systems is used. A popular method is for the birds to be brooded in wire-floor tier brooders indoors, transferred to hay-box folds at three or four weeks of age, and to covered fold yards at eight weeks.

Turkeys are brooded in a similar manner to chickens. The only special points are that poults need a slightly higher brooder temperature than chickens for the first fortnight, and a bright light over the food troughs is essential for the first few days. Turkey poults cannot see well when hatched, and a major cause of losses can be traced to inadequately lit brooding quarters.

Evidence indicates that after the six to eight weeks-old stage, turkeys thrive better in open-sided buildings with ample fresh air, than in elaborate broiler type houses. This means that they can make a useful crop to put through a building which may be otherwise out of use for part of the year, such as a covered yard. Alternatively, special pole barn type structures can be cheaply constructed (Plate LIXB).

Plenty of floor space should be allowed, 4 sq. ft. per bird at sixteen weeks, and 5 sq. ft. at twenty-two weeks.

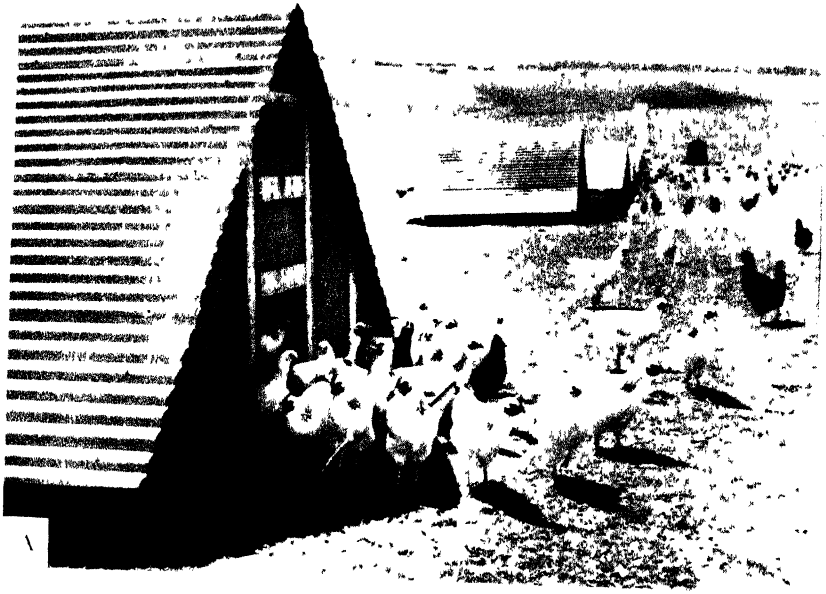
Turkeys can also be grown on wire or slats, and outdoor units known as "turkey verandahs" are often used. These house about 30 birds and have slatted floors situated about 2 ft. from ground level. They have an enclosed sleeping compartment and an open-sided run: 3 sq. ft. per bird is usually allowed.

Feeding. Young turkeys require higher levels of protein, vitamins and trace elements in a ration than most other classes of stock. Their rations are therefore usually more expensive, but under no circumstances should an attempt be made to cheapen turkey rations by feeding inferior foods.

Ad lib. feeding of mash or granules is usually practised for the first six to eight weeks, with grain being introduced at this stage. In many cases elaborate feeding programmes involving the use of four or five different types of rations at different stages of the birds' growth are adopted.

A simple feeding plan which has been proved to give good results in practice consists of giving the birds a "starter" type ration throughout their life, but diluting this more and more with grain as the birds grow. Whole grain can be introduced at four to six weeks of age, and can form up to one-third of the total diet at sixteen weeks of age, and one-half at twenty weeks.

Adequate trough space is important, and 4 in. per bird should be allowed at twenty weeks. The troughs should be wasteproof as turkeys, unlike chickens, do not pick up spilt food. For this reason



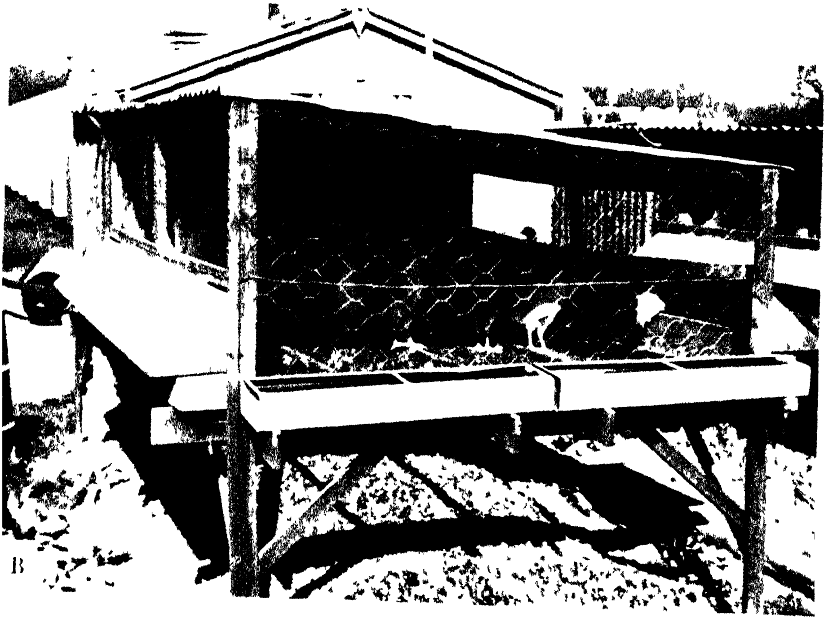


PLATE LVI

A Heavy-breed Pullets on Range

B Pullets in wire-floor Outdoor Units

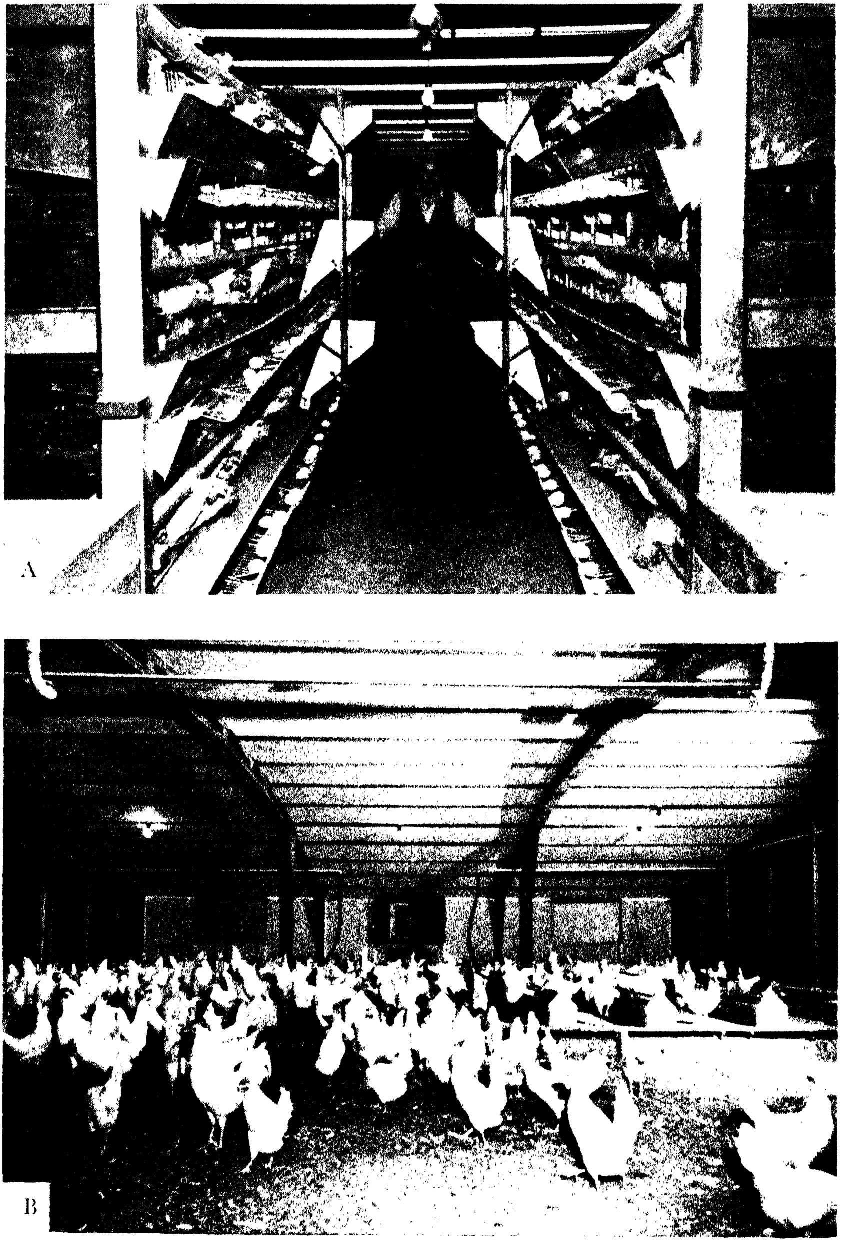


PLATE LVII

A. Feeding Caged Layers

B. Breeding Stock on Deep Litter

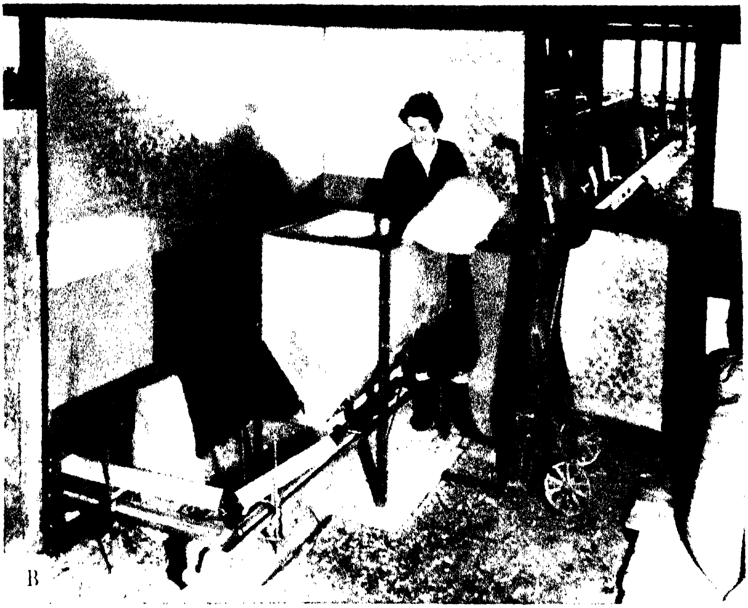


PLATE LVIII

A. Hybrid layers on Wire Floors

B. Filling the Hopper of a Mechanical Feeder

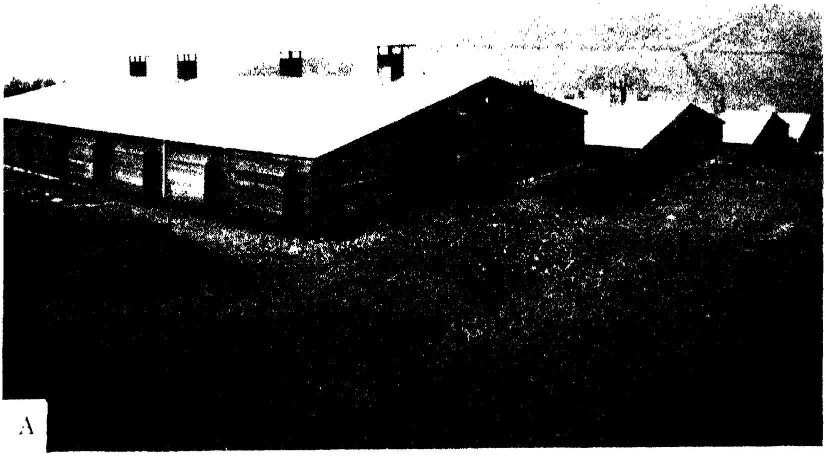


PLATE LIX

A. Windowless Broiler Houses

B. Bronze Turkeys housed in a cheaply constructed Pole-barn also, grain should be fed in troughs and not scattered in the litter.

Turkeys like food and water troughs which do not impede the movements of their heads.

Small amounts of insoluble flint or granite grit should be fed twice a week to all turkeys.

Management and Disease Control. Perches are not usually advisable where turkeys are being reared in covered yards or pole barns. Regular addition of fresh straw or other litter is essential, preferably twice weekly or more often if the litter gets wet quickly.

Turkeys are usually bought " as hatched " and sexing is difficult until they are ten to twelve weeks old. At this age the birds undergo a process known as " shooting the red ", i.e., begin the development of the comb and wattles. Stags can usually be distinguished at this age by the development of the protrusion above the beak known as the *snood*, and by their larger size and masculine appearance. It is preferable to separate the sexes at this stage.

The inclusion of preventative levels of drugs in the food or water against Coccidiosis, Blackhead, and Salmonella diseases is now common practice. Of these diseases Blackhead is still the major risk, and regardless of whether a drug is used or not, the best method of control is the immediate isolation of sick birds, and the regular renewal of fresh litter materials.

Marketing. Most turkeys are sold between the ages of twenty and twenty-four weeks, and the majority are still killed in the month or so before Christmas. Many wholesalers and packers are willing to take birds throughout the year, and this is a growing trend. Most of these out-of-season birds are plucked and cold stored until Christmas, and in some cases the producer is paid outright for them, whilst in others he may be paid an interim sum, with the remainder to follow after Christmas.

Turkeys may be sold off the farm at liveweight, or plucked, and in some cases eviscerated. Killing is normally done by dislocation of the neck, and plucking carried out by hand. Birds should be starved for about twelve hours before killing.

The following average weight losses occur during processing: Killing and plucking, 4–7 per cent, Trussing (including bleeding if birds bled separately) 14–18 per cent, giving total losses equal to 20–25 per cent.

Large birds will lose proportionately less than small ones.

Immature Turkey Production. The demands by the consumer for a 10–15 lb. carcase, and by the producer for a better food conversion rate, have led to an increasing trend towards the killing of large-type turkeys at earlier ages, usually at fourteen to sixteen weeks. Broad-breasted strains of Bronze or Whites are normally used for this.

Average liveweights of 10–12 lb. for females, and 14–16 lb. for stags at sixteen weeks can be achieved with the right stock and good management. The system requires quick growing, broad-breasted stock, a minimum number of housing changes, and adequate housing shelter from extreme weather conditions.

A higher energy/protein diet throughout the whole of the birds' lives is necessary, and in some cases special " finisher " diets containing fat are used for the last three or four weeks. Caponising of the stags is carried out three weeks before killing with two 15 mg. pellets of stilboestrol or hexoestrol ; the hens receive one 15 mg pellet, three weeks before killing.

TABLE DUCKLING PRODUCTION

This is a specialised industry producing ducklings for the luxury market ; it is still fairly localised in extent, in that most duckling production is centred on Norfolk and East Anglia.

The ducklings are purchased at day old, and the three main breeds used, in order of importance, are the White Aylesbury, the Pennine and the Pekin.

Heat is only required by the ducklings for the first ten to fourteen days. After this short brooding stage they are mostly transferred to portable solid floor houses, with attached grass runs.

The birds are fed special duckling rations in the form of wet mash or pellets. They are usually sold at eight to ten weeks of age, and will weigh 6-8 lb. Food conversion rates are usually good, figures of below 3½ : 1 being common.

Ducks are easily upset, and successful management requires quiet careful attention.

GEESE

Geese are seldom kept in large numbers, but small breeding flocks of three or four females and a gander are found on many farms. The chief breeds are the Embden and the Toulouse, both of which are large in size with adult ganders weighing around 30 lb. and females 20–22 lb. Other breeds seen occasionally include the Chinese, the Roman, and the Sebastapol.

Geese lay three or four clutches of eggs in a season, commencing in February or March. These eggs take twenty-eight to thirty days to hatch, and on most farms the incubation is done naturally by the female geese or by broody hens. Where larger numbers of eggs are available, electric or oil heated still-air incubators are often used. A 150-egg size machine will take about 40 goose eggs.

Brooding is mostly done by the female goose or broody hen. If artificial brooding is necessary, 15-20 goslings may be placed in a 100-size chick brooder. Artificial heat is only required for the first two to three weeks.

After the brooding stage to six to eight weeks the young geese are normally run in flocks on grass range. Little supplementary feeding will be necessary during the spring and summer if the geese have access to ample short herbage. When the grass has stopped growing, grain and mash feeding should be introduced. Geese will also eat green and root vegetables such as cabbages, turnips and fodder beet. About one month before killing, the amount of grain or fattening mash should be increased.

Geese are voracious grazers, and in average conditions 15–20 birds per acre will be the maximum stocking rate.

COMPOUNDING RATIONS FOR POULTRY

In principle the compounding of balanced mashes for poultry consists of blending together ground cereal grains, suitable protein concentrates, minerals and vitamins in proportions that are appropriate for the particular class of stock for which the mixture is intended.

The cereals used will consist mainly of wheat, barley, oats and maize, ground suitably to fine meals with the exception of wheat, which should be coarsely ground because of its tendency otherwise to become pasty in the bird's beak. A certain amount of fine wheat offals may be used if desired as an aid to obtaining a rather more palatable " open " texture in the food.

Protein concentrates must be highly digestible and of good quality. These include the animal proteins—fish meal, meat meal and meat and bone meal ; and the better vegetable proteins such as decorticated ground nut meal and soya bean meal. Some animal protein is desirable in all poultry rations. Bean meal and pea meal are useful alternative vegetable protein foods, but are of only intermediate value in protein content, combining this with a useful " energy " value as well.

The minerals normally required, in addition to those already present in the cereals and protein foods, consist primarily of calcium, phosphorus and chloride. These can be provided in the forms of chalk (or limestone flour), steamed bone flour (or dicalcium phosphate) and common salt.

Most of the minor elements required by poultry will be present in sufficient amounts in the basic food ingredients, but it is advisable to include a small quantity of additional manganese, particularly for young chicks, breeding stock and most classes of turkeys. Many brands of suitably balanced mineral mixtures containing these substances in correct amounts are readily obtainable, and offer a convenient method of providing the necessary minerals.

For all poultry, other than growers and commercial laying stock running at grass during late spring and summer, vitamin supplements are essential. Without them intensive poultry keeping would not be possible. Intensively-housed birds of all ages and classes at all times require supplies of vitamins A and D_3, as also do extensively kept birds during the late autumn and winter months. These two vitamins can be purchased, combined together either as " dry " vitamin supplements or, alternatively, in the form of stabilised fish liver oils.

Good quality grass meal contains the substance called carotene, from which the bird can synthesise vitamin A, and for this reason alone is a valuable ingredient in poultry rations. In addition it contains other minor factors and also helps to impart a rich colour to the egg yolk.

Some classes of poultry require additional supplies of riboflavin (vitamin B_2). These include young chicks, breeding stock, broilers and turkeys of all ages. Unextracted dried yeast and dried milk are rich sources of riboflavin, and this vitamin can also be purchased in pure concentrated form conveniently incorporated into one common supplement with vitamins A and D_3.

Suitably balanced mashes can be prepared in a great many ways, employing a variety of combinations of the several ingredients in correct proportions. Some practical examples are given in the tables which follow, together with some notes on ways in which the formulæ may be varied without materially affecting the balance of the mixtures.

These specimen formulæ can be modified in a number of ways without materially interfering with the adequacy and "balance" of the food.

For example, the proportions in which the various cereal grains are used may be varied somewhat, bearing in mind that barley meal is slightly lower in energy value than wheat and maize is somewhat greater. Oats are more fibrous than the other grains and, although they may be used in larger quantities in mashes for older birds, they should be well ground and their greater level of usage counterbalanced by a reduction in the quantity of wheat offals used.

TABLE 18

SPECIMEN MASH FORMULAE FOR CHICKS, GROWERS, LAYERS AND BREEDERS

(Quantities are for approximately 10 cwt. mixes of all mashes)

	(A) Baby Chicks (0–8 weeks).	(B) Growers.	(C) Layers (Intensive Winter).	(D) Grain Balancer (Intensive or Winter).	(E) Battery (All mash).	(F) Breeders.
Fine Wheat Offals	2 cwt.	2 cwt.	2 cwt.	2 cwt.	2 cwt.	2 cwt.
Coarsely-ground Wheat . . .	2½ ,,	2½ ,,	2½ ,,	2 ,,	2½ ,,	2½ ,,
Ground Barley .	1½ ,,	3 ,,	2 ,,	2 ,,	2¼ ,,	2 ,,
Finely-ground Oats . . .	½ ,,	1 ,,	1 ,,	1 ,,	1 ,,	1 ,,
Maize Meal . .	1½ ,,	—	—	—	—	—
White Fish Meal	1 ,,	¾ ,,	1 ,,	1¼ ,,	¾ ,,	1 ,,
Dec. Ground Nut (or Soya Bean Meal) . . .	½ ,,	½ ,,	½ ,,	¾ ,,	½ ,,	¼ ,,
Unextracted Dried Yeast . . .	40 lb.	—	—	—	—	35 lb.
Dried Grass Meal	½ cwt.	—	½ ,,	¾ ,,	½ ,,	½ cwt.
Minerals . . .	28 lb.	20 lb.	35 lb.	50 lb.	35 lb.	35 lb.
Vitamin Supplement . . .	5 ,,	5 ,,	5 ,,	8 ,,	5 ,,	5 ,,

Where peas or beans are available at favourable prices they may be ground and used as alternatives to ground nut or soya bean meal in most rations, although they are not favoured in rations for very young birds. Peas and beans are of intermediate protein value, containing only 22–24 per cent or thereabouts. One hundredweight of either will replace half a hundredweight of ground nut or soya bean meal and half a hundredweight of one of the ground cereals.

The value of grass meal for poultry is confined mainly to its vitamin and pro-vitamin contents together with its capacity for producing good egg yolk colour. Inferior quality grass meals are value-less for poultry ; only high quality samples should be used. A protein content of not less than 18 per cent is a fairly good criterion of quality in well prepared and carefully-packed samples of grass meal.

TABLE 19

SPECIMEN RATIONS FOR BROILERS

(*approximately 1 ton lots*)

	Starter Rations (0–7 weeks).		Finishing Rations (7 weeks—killing).	
	(A) Standard (No added fat).	(B) High Energy (Fat fortified).	(C) Standard (No added fat).	(D) High Energy (Fat fortified).
Fine Wheat Offals . .	3 cwt.	3 cwt.	3 cwt.	3 cwt.
Maize Meal	6 ,,	4½ ,,	6 ,,	5 ,,
Coarsely Ground Wheat	5 ,,	4 ,,	6 ,,	5 ,,
Stabilised Fat . . .	—	1 ,,	—	1 ,,
White Fish Meal. . .	2 ,,	2½ ,,	1½ ,,	2 ,,
Dec. Ground Nut (or Soya Bean Meal) . . .	2½ ,,	3½ ,,	2 ,,	2½ ,,
Dried Grass Meal . .	½ ,,	½ ,,	½ ,,	½ ,,
Unextracted Dried Yeast	65 lb.	75 lb.	65 lb.	75 lb.
Minerals	45 ,,	45 ,,	45 ,,	45 ,,
Vitamin Supplement .	10 ,,	12 ,,	10 ,,	12 ,,

TABLE 20

SPECIMEN MASH FORMULAE FOR TURKEYS

(*Quantities given are for 10 cwt. lots of all mashes*).

	(A) Poult Starter (0–10 weeks).	(B) Growers' Mash (Intensive).	(C) Finishing Mash (Final 3 weeks).	(D) Breeders' Mash.
Fine Wheat Offals . .	1½ cwt.	2 cwt.	2 cwt.	2 cwt.
Maize Meal	1½ ,,	—	—	—
Coarsely Ground Wheat	2 ,,	2½ ,,	2½ ,,	2½ ,,
Ground Barley . . .	—	1½ ,,	3 ,,	2 ,,
Finely Ground Oats .	1 ,,	1 ,,	1 ,,	1 ,,
White Fish Meal. . .	1¼ ,,	1 ,,	—	¾ ,,
Dec. Groundnut (or Soya Bean Meal) . . .	1½ ,,	1 ,,	¾ ,,	¾ in.
Dried Grass Meal . .	½ ,,	½ ,,	½ ,,	½ ,,
Unextracted Dried Yeast	40 lb.	20 lb.	—	40 lb.
Minerals	30 ,,	30 ,,	20 lb.	40 ,,
Vitamin Supplement .	5 ,,	5 ,,	5 ,,	7 ,,

(Grass meal and vitamin supplements may be omitted from rations for growers and layers on spring and summer range conditions).

Many mixed mineral preparations for poultry are obtainable, most of which are quite suitable for the purpose and may be included in rations at the levels indicated above. For those wishing to prepare their own mineral mixtures, a combination of 20 lb. limestone flour, 10 lb. steamed bone flour, 10 lb. common salt and 4 oz. of manganese sulphate would give a suitable mixture. It is important to see that the manganese sulphate is finely ground and intimately mixed with the common salt, which is then in turn thoroughly mixed with the other two ingredients.

The quantities given in the tables are based on supplements containing 800 units of vitamin A and 200 units of D_3 per gramme. These are the more common concentrates, but some supplements are of greater potencies and should be used in lesser amount according to instructions. For good quality cod liver oil the quantities required are normally double the amounts of the vitamin supplements given in the tables.

Should a synthetic vitamin B_2 (riboflavin) preparation be preferred instead of dried yeast, an additional amount of ground nut or soya bean meal, equal to the weight of dried yeast withdrawn, should be included in the ration to compensate for the loss of the yeast protein.

The above formulæ do not include antibiotics, other growth stimulants, coccidiostats or any other drugs. The use of such things is at the farmer's discretion, who should at all times abide by the instructions given for the use of such additives.

It is permissible to feed some grain with some of these rations under certain conditions. Grain feeding to birds under extensive conditions, especially growing stock, is necessarily arbitrary in character. But as a general guide, to rations in Table 18 some grain could be fed to growing pullets with ration (B), commencing at about ten weeks of age and gradually increasing in amount as the bird develops, up to a maximum of 2 oz. per day according to condition of the pullet and its environment. For layers of heavy breed or light/heavy crosses, a grain feed of up to 1½ oz. per head per day may be fed with rations (C) and (F), and 2½ oz. with ration (D). No grain should be fed with the all mash ration (E).

For the smaller hybrid layer it is recommended that ration (C) be used as an all mash ration in place of (E), and that (D) should be used as a normal mash instead of (C), fed in conjunction with a 1 oz. per day grain feed.

No grain should be fed with the turkey poult starter mash, nor in the earlier stages with the turkey grower mash, but a small grain feed can be introduced from about fourteen weeks of age during the growing-on period. Breeding turkeys may have 1½ to 2 oz. of grain per head per day according to size.

The broiler rations should be fed alone with no grain supplement at all.

Chapter XXIV

ANIMAL HYGIENE

Farm animals, like all living creatures, are subject to ill health of various kinds. To a large extent the increasing intensity of livestock production has brought its own problems in this respect ; increased production per animal or per unit of land subjects the animal to stresses which may make it more susceptible to disease. With the current emphasis on efficient livestock production, the financial loss occasioned by ill health cannot be dismissed lightly and attention must be paid to increasing the health standards of farm animals.

The annual loss to the British farmer caused by disease is extremely difficult to estimate. Losses due to the death of animals are readily apparent but, more often, the animal survives but its production falls below full potential. Sub-clinical disease may cause losses of production in animals which appear perfectly healthy. These losses due to reduced production far outweigh those due to fatal disease and are virtually impossible to estimate in financial terms.

Many farmers tend to accept ill health in stock as a normal hazard of farming but it seems likely that much of the loss of production caused by diseases could be prevented by paying greater attention to their prevention and cure. Much research has been devoted to the study of ill health and an increasing knowledge of the causes and effects of ill health has contributed to the control of certain disease conditions. Also, many new drugs have been discovered in recent years which have greatly changed veterinary practice.

It is unreasonable to expect the farmer to keep abreast of these developments and to have the technical skill to administer drugs which, though they can effect remarkable cures, can be extremely dangerous if incorrectly used. However, the farmer can do much to assist in reducing the incidence of ill health by good management and good feeding of livestock with attention to hygienic measures. Further, when ill health does occur, the early recognition of an abnormal condition and recording of symptoms can be extremely useful to the veterinarian in making a rapid and accurate diagnosis and treating the condition.

Symptoms of Ill Health. Often the first sign of ill health is that the animal isolates itself from the herd or flock, but any departure from normal should act as a warning to the stockman. There may be changes in appearance, posture or movement, or abnormalities of respiration, pulse rate, temperature, appetite, rumination in cattle and sheep, defaecation, urination, the œstrous cycle or productivity.

When ill health is recognised the animal should if possible be isolated to facilitate observations and to prevent the spread of infectious disease. Records should be taken of respiration rate, pulse rate and body temperature (which is recorded by inserting a clinical thermometer into the rectum). If these records are to be of use the animal should not be frightened or excited during the period of examination. Normal values as given by Wooldridge are set out below :

	Respiration Rate (per minute)	Pulse Rate (per minute)	Body Temperature (° F.)
Horse	8–16	28–42	99·5–101·3
Foal (1st year)	10–15	40–58	99·5–102·2
Cow	26–30	60–90	99·5–103·1
Calf (6 months)	30	100	102·2–104·0
Sheep, goat	10–20	68–90	102·2–104·9
Pig	10–20	60–90	100·4–104·0
Dog	14–30	60–130	99·3–102·2
Cat	20–30	110–130	100·4–102·2
Fowl	15–48	120–160	106·7–108·5

It is evident that both respiration and pulse rates show a range of normal variation, but gross abnormalities may indicate disease conditions. For example, rapid panting may be caused by diseases of the lung such as pneumonia or may be associated with a feverish condition. The normal range of temperature variation is smaller and many diseases are associated with a definite rise of temperature.

Other symptoms may also indicate ill health. The eyes, which are normally bright, may be dull or there may be a drooping of the head (or wings and tail in birds). The coat of cattle is normally glossy, i.e. it has a good " bloom ", but in animals in poor condition may be dull or " staring " ; in advanced stages of wasting diseases the fleece of sheep may fall from the body. Animals may show abnormalities of movement ranging from an inability to move to violent convulsions. Abnormal colorations of the mucous membranes lining the nose and other passages may be evident or there may be discharges from these passages. Diarrhœa, or the presence of blood in the fæces, may indicate specific diseases of the intestinal tract. Similarly, the urine which is normally a clear yellowish fluid, may be cloudy, brown or red. Sudden reductions in milk yield in dairy cattle may be early symptoms of ill health while an abnormal milk secretion, e.g. the presence of clots or of blood in the milk, is indicative of diseases of the mammary gland. Finally, there may be swellings of the body in different sites. These signs, occurring singly or in combination, can be symptomatic of specific diseases and therefore provide information which is of value to the veterinary surgeon in deciding on a course of treatment.

Occasionally more detailed examination of the animal is necessary, and this is normally carried out by the veterinary surgeon using special instruments and techniques. Often the exact cause of disease can only be established after laboratory examinations.

The Nature of Ill Health. Ill health may be the result of injuries or wounds, malnutrition, poisoning or attacks by specific infective agents. In some cases diseases are not readily transmissible from animal to animal and are described as being *non-infectious* ; in other cases disease may spread rapidly among a group of animals and is then described as being *infectious*. Disease is said to be *acute* when severe and of short duration, *chronic* when less severe but of long duration, *sporadic* when arising from occasional causes, and *epidemic* when widespread and arising from a general cause.

The causal agents of ill health are many and are listed below. (This list is not in order of importance).

(1) Injuries
(2) Poisons
(3) Fungi
(4) Bacteria
(5) Protozoa
(6) Viruses
(7) Helminths (worms)
(8) Acari (ticks and mites)
(9) Insects
(10) Nutritional deficiencies
(11) Metabolic disorders

Disease Resistance. It is a common observation that, when animals are exposed to an infectious disease, some contract it whereas others appear to be resistant. The role of the white cells or leucocytes in engulfing and destroying pathogenic micro-organisms has already been described (see p. 508), but the body has other means of defence against disease. Often, when an animal recovers from an infectious disease, there follows a period of immunity from further attacks. Clearly some reaction takes place in response to disease by which the animal develops an acquired immunity. This is due to the formation, from body proteins, of substances called *antibodies* which circulate through the body dissolved in the body fluids. The action of antibodies may be to kill or immobilise parasitic organisms, make them more susceptible to destruction by leucocytes or render their poisons innocuous. Antibody formation is particularly important in the development of resistance to attacks by bacteria and viruses, but antibodies are also produced in response to attacks by other parasites and, indeed, in response to the presence of almost any foreign substance in the body. The immunity is not always complete, for the supposedly immune animal may succumb if heavily challenged by disease or the immunity may fade with the passage of time.

Disease resistance has two important applications in the prevention of ill health. Firstly, it has been found that if a susceptible animal is dosed with blood serum from an animal which is immune to a certain disease, the antibodies contained in the immune serum confer resistance to that disease on the recipient. This is the principle of *immunisation* and immune sera are widely used to confer disease resistance on susceptible animals. The protection is only complete over a limited period of time after which the animal may again become susceptible. Secondly, it has been found that if the causal agent of a disease is inactivated (by treating it with heat or chemicals, or by irradiation) and injected into a susceptible animal, it stimulates the formation of antibodies without exposing the animal to the clinical effects of the disease. This is the principle of *vaccination* and the inactivated preparation of disease organisms is known as a vaccine.

In the case of immunisation, antibodies from the immune serum are responsible for the disease resistance, and immunity is acquired in a passive manner. However, when an animal is vaccinated immunity is acquired in an active manner, antibodies being produced by the animal in response to the presence of a foreign substance (the vaccine).

Legislation in Relation to Disease. Certain diseases have serious effects on the animal or may be a potential danger to humans eating livestock products from infected animals. Many such diseases have become subjected to legislative control measures, either to eradicate them completely from the country, or to control the incidence of sporadic diseases which might otherwise quickly overrun the country.

Under the Diseases of Animals Act (1950) the outbreak of certain diseases must be notified to the police ; these notifiable diseases include Anthrax, Foot and Mouth Disease, Sheep Scab, Swine Fever and Fowl Pest.

THE CAUSES, PREVENTION AND TREATMENT OF ILL HEALTH

In the following description the various types of ill health in farm animals are classified under headings according to their causal agents. Under each heading the main types of ill health are listed and a selection of these is described in more detail both to show how they affect livestock production and to illustrate principles of prevention and control.

INJURIES

An injury or wound may directly affect the level of production of an animal or it may allow infectious organisms to gain entry to the body. Generally, simple injuries such as cuts and bruises can be readily treated with antiseptic dressings and recovery is rapid and complete. However, if the injury is severe, e.g. a fractured limb bone, it is probably best to slaughter the animal rather than to pursue a tedious course of treatment which may never give complete recovery ; the latter course may be followed if the animal concerned is valuable.

One troublesome condition in cattle is caused by the presence of foreign bodies, such as pieces of wire or nails, in the rumen or reticulum. Cattle graze extremely rapidly and, if metallic objects are left lying in fields, they may be eaten and can lead to sickness because of inflammation of the internal walls of the rumen or reticulum, or death if the object happens to pierce a vital organ or blood vessel. Much can be done to prevent trouble from this cause by ensuring that wire, nails, etc., are not left lying in the field. Affected animals may show a spontaneous recovery, but it may be necessary for the veterinary surgeon to operate on the animal and remove the offending object.

POISONS

Many pathogenic organisms cause ill health by the production within the body of toxic substances, but the animal may consume foods and other substances which are themselves poisonous and cause sickness. Some poisons produce specific symptoms in affected stock whereas others cause more general symptoms, usually including vomiting and diarrhœa.

On many farms, poisonous substances are in routine use and may be accidentally eaten by stock with disastrous results. Stock may also be poisoned if they have access to water supplies which are polluted by chemical poisons, or poisons (such as fluorine) present in factory smokes may be deposited on pastures as fine dusts. Poisoning from this latter cause may make it impossible to keep grazing stock in the neighbourhood of certain chemical works. A common form of poisoning in housed cattle (especially calves) arises from them gnawing at lead paint which is flaking from wood work, or licking new paint. Much can be done to prevent poisoning by the careful storage, handling and disposal of poisonous substances.

Several weed plants have been stated to be poisonous to stock eating them, but these claims are often difficult to substantiate. Cases of poisoning may occur only when pasture is in short supply and animals are forced to graze in the hedgerows and ditches. Plants which are definitely harmful to stock include ragwort, hemlock, horsetail and bracken ; some of these retain their poisonous properties when made into hay. Buttercups are probably only poisonous when eaten in large quantities. Ragwort is scheduled as an injurious weed and must be controlled either by cutting or by the application of weedkillers such as MCPA or 2-4 D. Bracken and horsetail are both difficult to kill in pastures, but horsetail shoots can be tackled with herbicides, making the pasture safer for grazing or haymaking.

Yew poisoning can occur with serious consequences, and it is important that yew trees should be fenced off from stock, or felled.

Some crop plants may, under particular circumstances, be poisonous to livestock. For example, where kale or rape are being extensively grazed by sheep or cattle poisoning may occur, the main symptom being the presence of blood in the urine. Similarly, freshly cut sugar beet tops may cause poisoning : they are quite safe for feeding if allowed to wilt for a few days.

In some areas of the world mineral substances such as molybdenum and selenium are present in relatively high concentrations in the soil. Under these conditions plants which are normally quite safe for feeding may accumulate excessive quantities of these substances and cause toxic effects in grazing animals. The only common type of poisoning of this sort in this country occurs on the so-called " teart " pastures of Somerset and Warwickshire where grazing animals fail to thrive because of the consumption of excessive quantities of molybdenum.

DISEASES CAUSED BY FUNGI

The only common condition resulting from fungal attack is Ringworm which, in farm animals, is most prevalent in calves and yearling cattle ; older cattle appear to be resistant.

The fungus grows in the superficial layers of the skin and results in the formation of bare circular patches, especially in the region of the head and neck. It may not have any obvious adverse effects on the animal but can cause severe irritation and leave ugly blemishes on the skin. Probably more important is the fact that the fungus can attack human beings in contact with infected stock in whom it produces highly irritant lesions.

Calves frequently show a spontaneous recovery from ringworm as they grow older, but the resistant spores produced by the fungus are harboured in buildings and infect subsequent occupants. The treatment of infected areas of the animal with tincture of iodine is often effective in curing the condition but is tedious ; modern antifungal agents such as compounds of benthiazole seem to offer a more effective and simple means of control.

DISEASES CAUSED BY BACTERIA

Bacteria are small unicellular organisms belonging to the plant kingdom and are present in enormous numbers in the body. Some types of bacteria may be present without causing disease and may be actually beneficial, e.g. bacteria in the rumen, but others may gain entry to the body where they multiply rapidly and cause disease. The diseases caused by bacteria include anthrax, bovine tuberculosis, brucellosis of cattle, infectious scours of calves, Johne's disease, mastitis, pulpy kidney and lamb dysentery of sheep, tetanus or lockjaw, braxy of sheep, foot rot of sheep and bacillary white diarrhœa (B.W.D.) of poultry.

Anthrax. This disease is caused by *Bacillus anthracis*, and all farm animals (except the hen) are susceptible. The disease is acute, and death is usually the first symptom, the body being grossly distended with gas and the limbs stiff. Anthrax is a notifiable disease, and whenever an animal dies suddenly showing the signs described above a veterinary surgeon should be called at once. It is extremely dangerous to open the body of an infected animal because the bacteria are released and form resistant spores which can live in the soil for several years, thus forming a centre of infection for other animals. If, however, the carcase is buried without being opened, the bacteria die within a few days. Apart from the effects it has on farm animals, the disease is important because it can be contracted by the human.

Bovine Tuberculosis. Tuberculosis has for many years been a most important disease causing a wasting condition of cattle with great losses of production. Further, pigs and, more important, humans consuming products from infected animals, may become infected. Tuberculosis is caused by *Mycobacterium tuberculosis*. The owner of an animal known to be shedding tuberculosis germs is legally bound to report this to the police.

Some control of the incidence of tuberculosis in humans has been achieved by the pasteurisation of milk, but the most important contribution to the control of the disease in both cattle and humans has been the eradication of tuberculosis from the cattle of this country. After several campaigns to eradicate bovine tuberculosis a complete eradication scheme was adopted in 1950 which planned to tackle the problem on an area basis. Infected cattle were detected by a tuberculin test which distinguishes between cattle infected with bovine tuberculosis and those having non-specific infections, e.g. the avian form of the disease and skin tuberculosis. Cattle infected with bovine tuberculosis were disposed of while those having non-specific infections could be retained in the herd. In the early stages of the scheme farmers were encouraged to co-operate by the payment of a bonus on tested animals or milk produced from them, but in the final stages of eradication from an area, testing became compulsory. The eradication scheme was completed in 1960 and has made an important contribution towards improving the health of both the cattle and human populations.

Brucellosis or Contagious Abortion. Brucellosis, caused by *Brucella abortus*, is a most important disease of cattle causing abortion in the fifth to seventh months of pregnancy; abortion may be restricted to odd animals in the herd but there may be " abortion storms " in which many cows abort over a short period. Also *Brucella abortus* causes occasional cases of undulant fever in humans drinking milk from infected cows. The disease can cause considerable financial loss to the dairy herd, not only because of the loss of calves, but also because of the delay in breeding and loss of milk production which it entails. Infected animals generally abort only once and then become resistant but continue to act as carriers of the disease ; infection appears to be spread from animal to animal from bacteria present in discharges from the genital tract, and from fœtus and after-birth being dragged across fields by dogs and foxes.

Infection can be detected by a blood test, but often the infection is so widespread in a herd that control of the disease by the disposal of infected animals is impracticable. Fortunately a vaccine, called Strain 19 or S.19, has been available since 1942 and the routine injection of this vaccine into all heifer calves in the herd at about six months of age effectively suppresses the disease. In herds where Strain 19 vaccine is used routinely, results suggest that the vaccine merits even wider use than at present.

Infectious or White Scours of Calves. Young animals, whilst they are in the liquid feeding period, are frequently subject to digestive upsets which result in scouring. Scouring does not necessarily indicate the presence of pathogenic organisms—it may be merely a result of overfeeding or, in the case of bucket-fed calves, a poor feeding technique. However, pathogenic organisms may be the cause of digestive disturbances, and scouring due to infections with *Escherichia coli* can have serious consequences. Infectious scours are most prevalent in bucket-fed calves in which there develops a grey, evil-smelling diarrhœa and a rapid loss of condition frequently resulting in death. The disease can become serious where calf rearing takes place in unhygienic surroundings and where feeding equipment is not thoroughly cleaned after use. Much can be done to reduce the level of infection by thorough cleaning and disinfection of calf houses between batches of calves.

The first milk or colostrum produced by the cow contains antibodies which give the calf a measure of protection against infectious scours. It is therefore important to ensure that each calf receives colostrum at birth.

Treatment of seriously affected calves is often ineffective, but treatment with antibiotics such as aureomycin or terramycin as soon as scouring begins usually effects a rapid cure. Indiscriminate use of these substances may lead to the development of strains of disease organisms which are resistant to the bactericidal effects of antibiotics ; for this reason antibiotics should only be used under veterinary supervision.

Foot Rot. Of the conditions causing lameness in sheep the commonest results from infections with *Fusiformis nodosus* which causes an evil-smelling putrefaction of the soft tissues of the feet. The lameness interferes with grazing and may therefore result in a loss of body condition.

The bacteria can be killed by treating infected feet with tinctures of chloromycetin, but this product is probably too expensive except for use in serious cases ; the most usual method of control is to walk infected sheep through a foot-bath containing a 5–10 per cent solution of formalin or copper sulphate. Whatever system of treatment is used it is important that it should be preceded by paring off infected tissue with a sharp knife so that the bactericidal agent can gain access to the sites of infection.

It is known that the bacterium cannot live in the soil for more than fourteen days but can be carried indefinitely on the feet of infected sheep. These facts make the eradication of the disease possible. The feet of all sheep in the flock should be examined, infected tissue pared off with a sharp knife and the sheep (including those which appear to be healthy) walked through a foot-bath containing a 10 per cent solution of formalin. After treatment the sheep should be moved on to pasture which has been kept clear of infected sheep for at least fourteen days. This treatment should be repeated at intervals of one to two weeks until no further cases of foot-rot are present. Once a flock is free of foot rot infection can only be contracted if infected sheep are brought on to the farm.

Mastitis. This is a disease which can be contracted by all lactating animals but is probably most troublesome in dairy cows. There are several causal organisms, the commonest being *Streptococcus agalactiae*. Generally there is a swelling of the infected quarter of the udder, the milk from which is watery and contains hard ropy clots. Infection spreads from cow to cow via the milker's hands or the teat cups of the milking machine, and it has been noted that cows which milk-out rapidly are particularly prone to the disease.

Treatment of mastitis by the intramammary injection, over a period of four days, of penicillin, streptomycin or combinations of these two antibiotics, generally effects a cure. When this type of therapy is used, milk from treated quarters should not be marketed for three days after treatment ceases, or the presence of traces of antibiotic may have adverse effects on humans consuming such milk. The spread of infection in a herd can be checked by the use of a strip-cup so that mastitis can be recognised at an early stage : infected cows can then be isolated and milked separately from the main herd until cured. Also, careful use of the milking machine, particularly the avoidance of leaving the machine on the cow after milk flow has ceased, can do much to reduce the incidence of this troublesome disease.

A particularly serious form of mastitis occurs in heifers and dry cows, usually when the weather is hot and sultry. It is caused by *Corynebacterium pyogenes* and, because of its occurrence during the summer months, is called *Summer Mastitis*. The results of infection are serious ; there is an acute swelling of the infected quarter (which is usually permanently lost for milk production) and a feverish condition. Some cases may be fatal. There is, as yet, no completely effective treatment for this form of mastitis.

DISEASES CAUSED BY PROTOZOA

Protozoa are microscopic, unicellular animals and cause two important diseases in farm animals ; firstly, coccidiosis which can occur in various classes of stock but is most important in poultry ; and, secondly, blackhead of turkeys.

Coccidiosis. This is caused by a protozoan parasite (*Eimeria tenella*) which can infest the cæcum of chicks during the first few weeks of life and may cause high mortality rates. In the early stages of the disease the birds become listless, standing with their feathers ruffled, and pass bloodstained droppings. In serious attacks the first sign of coccidiosis may be the death of birds. These acute forms of the disease are known as cæcal coccidiosis but older birds can be affected by a chronic form which causes a loss of condition and reduced egg production.

The occurrence of coccidiosis can be prevented by the inclusion, in the feed or drinking water, of such substances as sulphamethazine and sulphaquinoxoline. Research is continually leading to the discovery of new and more effective coccidiostats. These can be used continuously as a preventive at half level of inclusion.

DISEASES CAUSED BY VIRUSES

There are several diseases in this group including three important notifiable diseases—foot and mouth disease, swine fever and fowl pest. Two other virus diseases, which occur in sheep, are orf (contagious pustular dermatitis), and enzootic abortion or kebbing.

Foot and Mouth Disease. Foot and mouth disease is highly infectious and can be contracted by cattle, sheep and pigs. Infected animals become feverish and develop blisters in the mouth which cause them to salivate abnormally freely, and on the feet, causing lameness. Death does not usually occur, but the disease is important because it leads to a tremendous loss of production and can quickly spread over large areas.

The disease occurs as sporadic epidemics in this country, being transported into Great Britain from countries where foot and mouth disease is endemic, either in imported meat or, perhaps, by migrating birds. The disease is notifiable and is controlled by the rigid enforcement of a slaughter policy ; all cattle, sheep and pigs on an infected premises, whether infected or not, are slaughtered and standstill orders are imposed on the movement of livestock within areas of possible infection. Under this policy the farmer is paid compensation for any non-infected animals slaughtered but, in the case of pedigree herds or flocks, this falls short of the potential value of breeding stock.

Vaccines are available which give some measure of protection against the disease and it has been argued that the routine use of these vaccines should supplant the present slaughter policy. Unfortunately there are various strains of the virus causing foot and mouth disease, and it is difficult to produce a vaccine which is completely effective against all these strains. Also, the vaccines at present available are only effective over a relatively short period of time and periodic vaccination of all farm mammals would be necessary. It seems that the slaughter policy is less costly on a national scale than periodic vaccination. The development of more effective vaccines would, of course, completely alter the situation.

Any condition which resembles foot and mouth disease should be reported immediately to the police.

Swine Fever. This again is an infectious virus disease but occurs only in pigs. Swine fever may be accompanied by a wide range of symptoms, from an acute form in which sudden death occurs, to a chronic form where pigs are ill for long periods. Even in the acute form there are usually warning signs of the onset of disease. Affected animals become uneasy, fail to feed, have a catarrhal discharge from the eyes, and body temperature is elevated to 106–108° F. In the acute form these signs are quickly followed by the development of a grey, evil-smelling diarrhœa and animals become abnormally thirsty ; there may be a reddening of the skin covering certain regions of the body. From this stage the pig declines rapidly in condition and dies within a few days. In the chronic form of swine fever the animals lose condition and have diarrhœa but may not die.

If the disease is suspected immediate advice should be sought so that a diagnosis can be made and rapid action taken. Swine fever is not a disease which spreads rapidly over whole areas ; infection takes place by pig-to-pig or pigman-to-pig contacts. The disease is notifiable but there is no enforced slaughter policy. Infected pigs are usually slaughtered, and it is wise to obtain a special licence to have slaughtered all growing pigs which can be used for meat purposes ; in this way the financial loss occasioned by the disease can be minimised. Breeding stock may also be slaughtered, but this is not usual, particularly where breeding animals are valuable. The usual practice is to retain non-infected breeding stock and give them protection against the disease by the injection of an immune serum. The movement of stock from infected premises is not permitted except by special licence, and before restocking with pigs the premises must be thoroughly disinfected. Compensation is paid only for those pigs which are taken for post-mortem examination.

There are two methods of helping to prevent an outbreak of swine fever. Firstly there is a vaccine, known as the crystal violet vaccine, which normally gives pigs good protection against swine fever. There is a strong case for using the vaccine for all breeding stock. Secondly, a common source of infection is inadequately boiled swill containing offals from infected animals ; a legislative order requires that all swill should be boiled for one hour before it is fed and this should be strictly complied with.

Fowl Pest (Newcastle Disease). This virus disease is highly infectious and may occur in flocks where there has been no apparent contact with diseased stock. The disease occurs mainly in fowls but can also be contracted by turkeys.

Fowl pest may occur in two forms, an acute form and a mild form (which in recent years has become more common than the typical acute form). In the acute form of the disease birds may be found dead without warning symptoms and over 90 per cent of an affected flock may die. Death may be preceded by symptoms including a loss of egg production, the development of a greenish diarrhœa, abnormal breathing with discharges from the nostrils and mouth, and sleepiness. The mild form of fowl pest resembles a nasal cold with the development of a watery diarrhœa. The infection spreads rapidly and there is a sharp fall in egg production though mortality (except in young birds) is low.

The disease is notifiable and its incidence is controlled by the rigidly enforced slaughter of all birds on an infected premises with compensation for any in-contact healthy birds slaughtered. The compensation does not cover the loss of egg or poultry meat production entailed in the slaughter of birds. After the slaughter of birds the supervised disinfection of an infected premises is carried out. In an attempt to prevent the disease spreading rapidly over large areas, there is a close restriction of the movement of poultry within an affected area.

HELMINTH OR WORM PARASITES

The general term, helminths, covers a range of worms parasitic on animals. The most important are the *nematodes* or round worms which inhabit the stomach and small intestine giving rise to a wasting condition known as parasitic gastro-enteritis. Other parasitic worms include those which inhabit the lungs, e.g. nematodes causing husk in cattle ; *tapeworms* which inhabit the small intestine ; and *flatworms*, e.g. liver fluke.

Parasitic Gastro Enteritis. This condition has been most widely studied in relation to the sheep. In the sheep several species of nematode worms inhabit the stomach and small intestine, including *Haemonchus contortus*, *Ostertagia circumcincta* and various species of the Genera *Trichostrongylus* and *Nematodirus*. In infected sheep these worms give rise to a progressive loss of condition, diarrhœa and anæmia. In some cases they may cause the death of sheep. Parasitic gastro-enteritis is mainly a problem of sheep less than one year old, (for after this age sheep develop a resistance to worm infestation), and where sheep are heavily stocked on pasture.

A knowledge of the life cycle of parasitic nematodes and the method by which sheep become infected is extremely important, for it can indicate methods of controlling the level of worm infestation by grazing management. It is known that the lamb is born quite free from worms but becomes infected from worms present in its dam or other infected sheep. Adult worms lay eggs in the digestive tract which pass out on to the pasture with the fæces. After a time the eggs hatch to produce larvæ which can infect sheep if they are taken in through the mouth in herbage. In most worm species these infective larvæ take from three to fourteen days to develop from the egg, but worms of the genus *Nematodirus* lay eggs which do not usually develop immediately but overwinter on the pasture and give rise to infective larvæ in the following spring. If infective larvæ are not taken in by grazing sheep then they usually die within a few weeks : in exceptional circumstances they may live for several months.

These facts relating to the life cycle of nematodes are clearly important in relation to methods of worm control. For example, to control *Nematodirus* it is important not to put grazing sheep such as susceptible lambs on pastures grazed by infected sheep in the previous season. If the pasture is rested from sheep grazing, the infective larvæ when they develop will be unable to find a suitable host and will die. Other species of worms can be controlled by breaking the life cycle in a similar manner. This involves the rotational grazing of sheep around small paddocks with the lambs being encouraged to *creep-graze* either forwards or sideways of their infected dams. In this way the lambs are given access to the best pasture available. The sheep are moved to fresh paddocks every three to six days so that, when the infective larvæ develop on grazed areas, no sheep are present to act as hosts ; by the time sheep return to graze areas which they have grazed previously, the large majority of infective larvæ will have died. These systems are so effective in preventing the build-up of worm infestation in lambs that stocking rates of 7 to 9 ewes and their lambs per acre can be achieved without adverse effects on the level of fat lamb production.

A number of substances have been discovered which will kill adult worms in the intestinal tract without unduly harming the sheep. The most widely used of these substances is phenothiazine (PTZ) which is effective against most species of worms except those of the genus *Nematodirus*. In recent years worm drenches containing biphenium embonate have been found to kill adult worms of the genus *Nematodirus*. These substances are all given to the sheep by oral dosing, but in 1961 the discovery of a new compound, methyridine, was reported which is effective against most species of worms and can be given by injection.

Liver Fluke (Fasciola hepatica). This flatworm is a parasite of sheep and cattle and spends part of its life cycle in a small snail which inhabits damp or wet areas of fields. Immature stages of the parasite develop in the snail and then leave it and form small cysts on the pasture. When these cysts are taken in with the herbage by grazing animals, they develop to the adult stage. The adult worm becomes located in the liver where it lays eggs which pass out on to the pasture and re-infect the snail.

The damage to the liver caused by liver fluke may be relatively slight and have no apparent adverse effect on the host animal ; but if a large infestation is present the liver damage becomes extensive and may cause unthriftiness or death. The disease may occur in an acute form which can cause death, often with no preliminary symptoms of infestation ; or in a chronic form in which the animal becomes anæmic and unthrifty though it may recover spontaneously ; occasionally there are epidemics of liver fluke disease with ruinous losses to the farmer. Apart from the direct effects of the disease on the animal there are indirect losses, because any liver in the abattoir showing signs of liver fluke infestation is condemned for human consumption.

The life cycle of the liver fluke suggests two possible means of control ; either the adult stages can be killed in the liver or the snail can be eradicated, thus breaking the life cycle. Control of the adult stages of liver fluke depends on dosing infected animals with capsules containing carbon tetrachloride ; these are given by mouth and care must be taken to ensure that the capsules do not burst in the mouth or throat of the animal for the fumes of carbon tetrachloride are extremely poisonous. Hexachloroethane is less toxic than carbon tetrachloride and can be used as an alternative. Recently it has been found that injections of carbon tetrachloride give effective control of liver fluke and are less dangerous to the animal than oral dosing.

The snail breeds in damp parts of fields, in ditches or near any water and the best method of reducing the population of snails is to treat such areas with 28 lb. of finely ground copper sulphate per acre. The treatment should be repeated two or three times during the summer months.

ACARI—TICKS AND MITES

Ticks and mites are troublesome external parasites affecting cattle, sheep, pigs and poultry.

Ticks. Although these parasites cause irritation and loss of condition in infested animals, they are probably most important as disease carriers. Among the diseases carried are red-water disease of cattle and louping ill and tick-borne fever (two important virus diseases which are most prevalent in sheep).

Ticks are most prevalent in upland areas and their life cycle is prolonged, taking place on a range of hosts. Although ticks can be controlled on farm animals by using dips, sprays or dusts containing benzene hexachloride (BHC), reinfestation quickly takes place from birds and wild animals which harbour the parasite (see p. 454).

Mites. Mites are probably the most important external parasites of this group. Equine parasitic mange and sheep scab, caused by mites, are notifiable diseases, but fortunately both appear to have been eradicated from this country. Mange still occurs infrequently in cattle and can be troublesome in poultry. DDT and BHC have been of enormous value in reducing the incidence of mange conditions caused by mites (see p. 455).

INSECTS

In hot climates insects are probably most important as carriers of disease, but in this country, although insects undoubtedly act as disease carriers, they are more important for the direct effects which they have on animals.

Many insects, such as house-flies and stable-flies, have mainly an irritant effect though they may also cause slightly reduced productivity. Some insects cause actual harm to stock and the most important of these are lice, keds, blow-flies (causing blow-fly strike in sheep) and warble flies. For fuller descriptions of these and the harm they cause, reference should be made to Chapter XIV.

Lice. There are two distinct types of lice ; biting lice which live on scurf and hair, and sucking lice which live on blood. Both types cause intense irritation and may give rise to bare patches on animals and birds. In cattle, sheep and pigs, lice are effectively controlled by the use of dips, sprays or dusts containing BHC, but in poultry it is more usual to treat the poultry houses than the birds themselves.

Keds. Keds are external parasites of sheep. They are wingless flies which suck blood, and the whole of their life-cycle is spent on the sheep. The irritation caused by keds may lead to the loss of parts of the fleece. Modern sheep dips appear to give effective control of this parasite.

Blow-Fly Strike or Myasis. Certain blow-flies, particularly a green bottle, *Lucilia sericata,* lay their eggs in fleece, and when the eggs hatch the maggots live on the flesh of the sheep. Apart from the intense irritation caused, the sheep may be literally eaten to death within a few days. Sheep may be " struck " at any time from May until late-September, but the incidence is highest in warm, humid weather. During this period sheep should be observed carefully for any signs of irritation denoting the presence of maggots in the fleece. Sheep may be dipped as a routine measure before any are affected, but as soon as a sheep becomes parasitised all sheep should be dipped using one of the modern dipping preparations (which generally contain BHC). It is compulsory to dip sheep once during the summer, and the operation should be supervised by a member of the local police. A single dipping gives protection against flies for several weeks but sheep may need to be dipped a second time later in the season.

Warble Flies. These flies are often called gad-flies though there are various other flies which cause cattle to " gad ". Adult warble flies appear in mid-summer and lay their eggs on the under-belly or on the legs of cattle. The eggs hatch to produce larvæ which burrow into the skin and wander through the body eventually becoming located beneath the skin of the back. In late winter the large grubs give rise to characteristic bumps on the backs of affected cattle and in spring or early summer the larvæ emerge through the skin and fall to the ground where they develop into adult flies.

The importance of these flies is first that the activities of the larvæ damage the skin of the back thus reducing the value of hides made from this skin : and second, the presence of the larvæ has a detrimental, if only slight, effect upon the growth and well-being of the infected animal.

The larvæ each make a small breathing hole in the skin, and the main method of control is to scrub the backs of affected cattle with a preparation containing derris which enters the breathing hole and kills the larva. This method of treatment does not eliminate the damage to the skin but reduces the population of adult flies in the following season. There is a legislative order which requires that all cattle should be treated in this way, but it is not rigidly enforced and is frequently disregarded by many farmers. It is hoped that, with the development of more effective warble fly dressings, especially organo-phosphorus compounds which are effective when given as skin dressings or by oral dosing, a more determined effort will be made to eradicate this pest and so eliminate the enormous spoilage of hides which occurs at present.

NUTRITIONAL DEFICIENCIES

The feeding of farm livestock can have marked effects on both health and level of production. The importance of feeding well-balanced rations in the right quantities has long been recognised. Both under-feeding and over-feeding are likely to have adverse effects on the animal. There are many constituents of rations, such as vitamins and various mineral substances, e.g. copper and cobalt, which are only required in minute quantities but are essential for normal health and production. It is possible for rations which appear adequate to be deficient in one or more of these dietary essentials and animals fed on such rations develop typical deficiency symptoms. In this respect, particular care must be taken in formulating rations for animals, such as pigs and poultry, which may spend the whole of their life indoors with no access to natural sources of vitamins and minerals.

For information on the importance and results of deficiency of essential vitamins and minerals, the reader is referred to Chapter XVIII.

METABOLIC DISORDERS

Current systems of livestock production often extend animals to the limits of their productive capabilities while expensive feeds are carefully rationed to prevent wastage. Under such systems of management there may be temporary disruptions of the normal metabolic processes of the body with serious effects on production and health. These disturbances may be called metabolic disorders. The most important metabolic disorders are : milk fever, grass staggers, acetonaemia, bloat and twin-lamb disease.

Milk Fever. Shortly after calving cows may become restless, pass into a comatose state and (if not treated) die. This condition, commonly called milk fever, is the result of an upset in calcium metabolism. In affected cows, blood calcium levels are sub-normal and so parturient hypocalcæmia is used as an alternative name for the disease. These low levels of blood calcium are not necessarily associated with low levels of calcium in the diet ; milk is rich in calcium and the sudden onset of lactation may use up the readily available body reserves of calcium whilst reserves of calcium in bone cannot be mobilised rapidly enough to maintain normal levels of calcium in the blood. The failure to mobilise calcium reserves from bone tissue is probably due to temporary malfunction of the parathyroid glands (see p. 517).

In former years milk fever was a common cause of death in dairy cattle but a completely effective remedy is now available. Affected cows are injected with a solution of calcium borogluconate and this effects a return to normal within a few hours.

Milk fever may also occur in lactating ewes and sows and the same method of treatment is used.

Grass Staggers, Hereford Disease or Hypomagnesæmia. This condition may occur in sheep or cattle and is characterised by a sharp fall in blood magnesium levels (hence the term hypomagnesæmia). Sudden death may be the first sign of the disorder, but usually the animal becomes restless with nervous twitching of the muscles and ears ; convulsive fits and death are later symptoms.

In many herds of cattle and flocks of sheep there is a steady fall of blood serum magnesium values during the late winter to critical levels (less than 2 mg. per 100 ml.) though animals show no outward sign of this. Grass staggers usually occurs when these animals are grazed on lush spring pasture though magnesium levels in the herbage are not necessarily sub-normal ; attacks are often precipitated by stress factors such as parturition, œstrus or spells of cold weather. Cases may also occur in autumn when pastures are sodden and the wet herbage causes animals to scour.

Formerly the occurrence of grass staggers was restricted to certain districts, being particularly prevalent in Herefordshire. In recent years cases have occurred in most areas, and the total number of cases, especially in dairy cows, has risen sharply. This increase seems to be associated with the intensification of grassland management, and it has been found that animals grazing pastures which have been dressed with potassic and/or nitrogenous fertilisers are particularly prone to attack ; the exact role of these fertilisers in relation to grass staggers is not yet fully understood.

In the early stages of an attack affected animals can be treated with injections of magnesium sulphate, and this effects a recovery in most cases. When animals are lactating it may be difficult to distinguish between the symptoms of grass staggers and milk fever, and for either condition it is usual to inject a preparation containing both calcium and magnesium. Preventative measures are of two kinds. Firstly, animals can be fed a supplement containing magnesium during the critical period just before being turned out and while they are grazing lush spring pasture. To do this, calcined magnesite should be fed at 2 oz. per day ; it may be necessary to mix the calcined magnesite with a little rolled barley or molassine meal to ensure that animals will eat it. Secondly, pastures may be top-dressed with dolomitic limestone (which contains magnesium) in an attempt to increase the magnesium content of the herbage. Both these measures markedly reduce the number of cases of grass staggers but do not necessarily eliminate the condition.

Acetonæmia (Ketosis). Acetonæmia occurs in the early weeks after calving and is generally restricted to high yielding cows which are being fed large quantities of winter rations ; it is rare in grazing cows. This is a disorder which is seldom fatal but which can cause a serious loss of milk production. The main symptom, apart from losses of milk yield and body condition, is a sickly smell of acetone in the breath. Acetonæmia is due to the accumulation of toxic ketone bodies in the blood ; these are produced as break-down products when fat is used extensively as a source of energy.

Cows normally show a spontaneous recovery after a short period, but this may be accelerated by oral dosing with ½ lb. per day of glycerine for four days ; it is claimed that oral dosing twice daily for three days with 1 oz. of potassium chlorate dissolved in 1 pint of water gives an effective cure.

Bloat or Hoven. When ruminants are grazing on good pasture, particularly those in which the proportion of legumes is high, the rumen may become so distended with gas that the animal has a " blown-up " appearance. Some cases may be fatal. It appears that the eructation or belching mechanism fails to function correctly and prevents the escape of gases produced as a result of bacterial fermentation in the rumen. In many cases eructation fails to eliminate gas from the rumen because of the formation, in that organ, of a stable foam in which the gas is trapped.

Various agents may help in relieving the condition, including various vegetable oils, animal fats such as tallow, antibiotics and anti-foaming agents. These all appear to function by preventing the formation of a stable foam. In New Zealand some farmers spray the area to be grazed on a particular day with vegetable oil or liquid paraffins ; it is claimed that this prevents the occurrence of bloat, but the practice is expensive. In severely affected animals it may be necessary to release gas from the rumen with a stomach tube or by puncturing the rumen by inserting a knife through the abdominal wall.

Twin-Lamb Disease (Pregnancy Toxæmia). As its name suggests, this is a disease which may occur in ewes bearing twin (or triplet) lambs ; it occurs during the last two weeks before lambing and usually the ewe and her unborn lambs die. The course of the disorder is swift —the ewe refuses to eat, becomes weak, shows nervous tremors, may be blinded and finally becomes comatose and dies. However, if an affected ewe lambs, she may show a dramatic spontaneous recovery. Twin-lamb disease may occur in pregnant ewes which are in poor condition but more often it occurs in ewes in good or over-fat conditions which meet a sudden nutritional check, e.g. through a change of diet, snow covering the ground, etc.

Affected ewes may have mild ketosis but the only consistent finding is low blood sugar levels which are responsible for the symptoms of the disorder.

It is possible to prevent serious attacks by ensuring that ewes are in steadily improving condition during the later stages of pregnancy and that they suffer no nutritional checks ; this can be achieved by supplementary feeding with a concentrate ration for the last six to eight weeks of pregnancy. Where cases do occur the most usual method of treatment is to give the ewe an oral dose of 4 oz. of glycerine, but some ewes fail to respond to this treatment. Recently, treatment with hormonal substances such as cortisone and glucagon has given promising results in some cases.

HYGIENIC MEASURES IN LIVESTOCK MANAGEMENT

Many of the diseases described in the preceding sections are highly infectious. It may not be possible to prevent the occurrence of these diseases but, if they do occur, it is essential to prevent them from spreading rapidly throughout the herd or flock. Many specific measures designed to control the incidence and spread of disease have been described, but there are also many routine measures, some of which are not very obvious, which can materially reduce the incidence of disease.

The Design of Livestock Housing. All too frequently in the past, livestock accommodation has been designed with little thought for the comfort and health of the animals which live therein. Buildings, especially those for young animals and pigs, should be well ventilated without being draughty. In piggeries the direction of air flow should be out over the dung passage rather than in the reverse direction for this will ensure that the pigs breathe fresh rather than foul air and helps to prevent the spread of infection within the piggery (see p. 61).

Efficient drainage is an essential requirement of all livestock buildings.

Equipment. Milking machines, udder cloths, calf-feeding buckets drenching bottles, hypodermic syringes and other equipment in regular use can provide the means of spreading disease from one animal to another. It is essential that equipment of this sort should be cleaned and efficiently sterilised after use.

Drinking troughs and bowls should be regularly cleaned out.

Foodstuffs. Mice and rats can be carriers of certain diseases, and wherever possible foodstuffs should therefore be stored where they cannot be spoiled by these rodents. In old storage buildings and barns where this is not possible, a determined effort should be made to reduce the population of rats and mice.

Feeding troughs should be so arranged that stock are prevented from fouling their food.

Isolation of Animals. Any animals brought on to the farm should be isolated until it is certain that they are free from diseases which might infect existing stock. Animals which are sick should be isolated for the same reason and so that they may be given special attention to ensure a speedy recovery.

If possible, animals recovering from a period of illness should be given a period of convalescence until they are completely fit to rejoin the herd or flock. During this period the animal should be fed small quantities of a highly nutritious diet and, in the case of grazing animals, daily access to good pasture may be valuable. In most circumstances gentle exercise is beneficial to the recovering animal.

The location and design of loose-boxes to be used for isolation purposes is most important. These should be situated as distant from healthy stock as is practicable and should be well ventilated (though not draughty) and easily cleaned. Cleaning is facilitated if the walls have a smooth rendering of concrete on their surface to a height of some five to six feet from the ground (see p. 77). So that animals can be easily examined and treated by the veterinary surgeon, it is essential to provide some means of restraining the animal.

Cleaning and Disinfection. It is necessary to clean thoroughly and disinfect isolation boxes immediately they become vacant ; the same is true of calving boxes, farrowing accommodation, permanent lambing pens and chick brooders and incubators. Diseases of calves such as infectious scours can be controlled by the regular cleaning and disinfection of calf houses.

In these operations cleaning must come first ; disinfectants are quickly rendered ineffective if they come into contact with large quantities of dirt. The bedding should be removed and, if an infectious disease has been present in the building, burnt. Then the walls and floors should be scrubbed and washed using plenty of clean water and a detergent ; special attention should be paid to cleaning fixed equipment in the building. When all dirt has been removed, disinfectant should be sprayed on the walls and floor. Many disinfectant materials are available including formalin, potassium permanganate, hypochlorites, carbolic acid, lysol, caustic soda and several proprietary disinfectants. Steam is used on many large poultry farms for the routine sterilisation of equipment.

If the disinfection of a premises is necessary after an outbreak of a notifiable disease, it is supervised by a veterinary officer of the Ministry of Agriculture, Fisheries and Food.

Stockmen. There is little point in employing hygienic measures on the farm if stockmen move at random between infected and healthy stock ; disease organisms can be carried on the person and clothing of stockmen. This method of spreading diseases is most difficult to overcome. The only general recommendation which can be given is that animals sick with infectious diseases should not be attended until work on healthy stock is completed. After attending to sick animals the operator should wash his hands and boots.

Chapter XXV

FARM ORGANISATION AND MANAGEMENT

THE word " management " is now one of the more widely-used terms in agriculture, but unfortunately it has different meanings to different people. To some, especially practical farmers, it means the day-to-day organisation of work on the farm. Is the ground fit for hoeing—if so, who shall do it—and so on. These decisions are aspects of farm management, but they are the immediate ones, akin to the tactical decisions a soldier must take in battle. In this chapter the term is used in its broader and longer term sense, comparable to the strategic decision of the soldier when he decides where the battle will be, and what the objective is once the battle is won. The farmer's day-to-day decisions should depend upon his type of farm organisation (which in turn depends upon his long-term objective) and not the other way round. It is for this reason that this chapter concentrates upon the principles and techniques required to plan and run an organisation rather than upon the problems of day-to-day management, vital though the latter is.

The Objective. The objective of the farmer is, in general, to make the most money, but within the bounds set by good husbandry. There may well be other objectives, however. To build up capital at the expense of present profits, or to achieve a certain status—perhaps to have a farm of a certain size, even if he could manage a smaller one better and make more money thereon. The farmer may not keep the livestock or crops that would make the highest monetary return because he gets a greater satisfaction from some other line of production—say bullocks rather than dairy cows ; or he may accept a lower profit in return for an easier life.

All these are quite valid choices, but for this chapter it will be assumed that the *objective of the farmer is to produce the maximum profit (difference between returns and costs) with the resources available to him, and within the bounds of good husbandry.*

FACTORS OF PRODUCTION

The farmer starts out with his various resources, including the farm itself, the potential of the land to grow crops, the buildings for storage and livestock, and so on. There is the capital that he can command, either from his own pocket or by virtue of his creditworthiness with banks and merchants. With this capital he can purchase different machines and livestock ; pay for all the productive resources he must buy (seeds, fertilisers and so on) ; and perhaps, most important of all, pay the wages of labour.

These form the three factors of production, *land*, *capital* and *labour.*

ORGANISATION AND CONTROL

The farmer has to *organise* the use of these factors to attain the objective set out above, and organisation is the first part of farm management.

But once he has organised his farm, he still has to see to it that the plan is carried out. This may seem so obvious as to be hardly worth saying, and so simple that there will be little chance of it not being done. But in many cases, failure to achieve a reasonable level of profit lies less with a poor plan than with poor execution of that plan. A typical example is the farmer who thinks that his dairy cows are being fed correctly just because he has produced a rationing scheme, without checking the actual amounts fed. Recent surveys have shown that only a minority of dairy farmers keep an accurate assessment of the concentrates fed. In other words, the best plan can be quite useless if no effective control is exercised during production.

Therefore the farmer sets out to farm his resources to the best of his ability, to produce as high a profit as possible, and he does this by organisation first, and control afterwards. In the following sections both these aspects are considered in some detail.

THE PRINCIPLES OF ORGANISATION

Land. The natural starting point for any farmer considering his plan will be the farm itself. Obviously, some farms are more suited to certain lines of production than others. Does a farmer choose a farm to suit a plan, or does he choose a plan to suit the farm ? While a man is looking for a farm, the first of these questions will be uppermost in his mind ; he will look for a farm that fits into the general pattern of what he wants to do, dairying, or extensive corn-growing, or mixed farming, perhaps. But once a farm has been selected, the detailed plan will be much more dependent on the potential of the land, its fertility and nature, the buildings and other facilities present. These aspects are mainly common sense, but a farmer should consider them in a logical order.

(*a*) **Soil and Climate.** In a temperate climate there is probably a wide range of crops or livestock that can be kept, but even so, some will be more suitable, in terms of physical yield at least, than others. Some soils are warm enough for early vegetables, others are not. Some soils are too heavy to have livestock treading upon them in winter, some are not.

(*b*) **Lay-out.** For some types of farming the lay-out of the holding is important. For arable cropping, provided there is reasonable access to fields, especially good roads in bad weather, the actual shape of the farm is not of prime importance. Indeed, many successful arable farms contain off-lying portions which are several miles away from the main steading. It is communications rather than proximity that matter most.

For a dairy farm, however, a compact lay-out is far more important. If some fields lie at a distance, or across busy roads, they will contribute less than they should to the general economy of the holding. On the other hand, communications in the form of hard roads are not nearly so important, for the livestock can move themselves across country with a fair degree of efficiency.

(*c*) **Buildings and other Facilities.** The type and condition of existing buildings may be very important in determining the plan. Some systems, such as dairying, are much more likely to require specialist structures than others. In the increasingly competitive future, certain buildings are likely to play an even greater part than they do now, for they are one way in which a farmer may overcome the scarcity of one factor of production—skilled labour, by using another—capital. In recent years great strides have been made in building design to save labour on certain farm operations, milking cows and corn storage being two obvious examples.

Other facilities may also be important, including power and water supplies. Electricity may be a most useful source of power for certain types of production, and to produce it on the farm, particularly for high loads, can be very expensive.

Good water supplies are essential for dairying and also for irrigation of crops. Indeed, ability to meet this last requirement may well add thousands of pounds to the value of a farm.

(*d*) Markets. In this country, where communications are good and the country is densely populated, access to markets is not often given enough consideration. Occasions arise when a farm may be suited to the production of some commodity by virtue of its soil and lay-out but have such poor communications as to render this line of production uneconomic. An example would be an island farm and milk for sale on the mainland. Again, because of some obstacle, even of a political factor such as war or tariffs, it may be more profitable to grow something that the farm is not really suited for, rather than another crop which is a more natural one. A special case may also arise where the farmer has access to a limited market, perhaps owing to personal reasons, where a special price can be made. This occurs most frequently in " quality " production.

(*e*) Size of farm. The size of the holding will also determine what production pattern is followed. A plan suitable for an 800 acre arable farm would not necessarily be reasonable for a farm of 80 acres even in the same district. This aspect can be considered more logically in the section on combination of factors.

Labour. The second factor of production, labour, is in some ways the most difficult to deal with because, behind all the discussion of principles and results, the answers have to be translated into human terms. The " units of labour " in dairy work, for instance, refer essentially to a real cowman, with human qualities and failings. However, bearing this point in mind, it is still possible to make a logical survey of the problems and characteristics of this factor as they affect the general farm plan.

(*a*) Availability. It is first of all essential to decide if the labour necessary for the plan is available. Certain products, notably field-scale vegetable production, require large quantities of manual labour at specific periods of the year. Therefore, to produce a plan for a farm where soil and markets suit this type of production, but where the necessary labour force does not exist, is adding complications to the plan. This scarcity might be overcome in various ways : transport from a town or temporary immigrant labour are two ways, but they both add to costs and management problems.

Another example is the stockman. Good cottages are virtually essential to attract and retain the type of labour who must stay on the job all the year round. If there is no such accommodation, transport from town will not provide the answer. Accommodation must be built or the enterprise dropped.

(*b*) **Methods of payment.** The normal way of paying for most farm work is *time wage*, where the man is paid a set wage for a standard week, plus overtime. If the weather is too bad to work outside, the wage must still be paid and hence much " maintenance " work on some farms is really only disguised " idle-time ".

The other main method is by *piece-work*. Here the worker is paid per unit of output—so much a ton picked or acre worked, etc. The main advantage of piece-work is that it links effort with output and rewards it accordingly. However, it can cause work to be skimped and arguments can develop over appropriate rates. Also, there are many routine jobs which do not fit into this pattern for payment, especially in stock-rearing, where care is vital.

An attempt to get the best of both methods lies in paying a standard time wage, plus a bonus linked to output where possible. Unfortunately, such schemes can defeat themselves by becoming too complex or arbitrary. With the sort of numbers usually involved on a farm, it is probably better for the farmer to pay a good wage to get good men and rely on his own personality to see that proper work is done at the right time.

(*c*) **Spasmodic requirement.** With crops, especially those with a high value per acre such as roots and vegetables, the requirements for labour are spasmodic, as noted above. This means, perhaps, that many men may be required to harvest the crop, while relatively few are needed at other times. If casual labour is not available to supply the bulk of this requirement, then the farmer who intends to grow these crops must consider whether he can afford to keep sufficient men to cope with this peak demand. If he can find other crops with a high demand at other times in the year, he may be justified in keeping a big staff, as in the Fens in this country.

Alternatively, he may be able to mechanise the process at the peak period—capital again substituting for labour. Or he may have to reduce his labour requirement by reducing, or cutting out entirely, the acreage of the particular crop which causes the problem. On the whole it is the high-value crops which have these labour peaks, and this makes the problem increasingly complex, because giving up the crop means going without a lot of potential income.

Capital. Capital represents both the fixed equipment of the farm, other than the land itself, and the money required to purchase the ingredients of production—livestock, seeds, fertiliser, machinery or labour. The former is called *fixed* or *landlord's capital*. The latter is known as *working capital*. The aim of the farmer should be to keep a reasonable balance between the two.

On the whole, working capital is not only more immediately productive, but it can be released and turned to other uses more quickly. Capital in the form of buildings or land can usually be realised only by selling up the farm. If a farmer decides that another line of production would be more profitable than his present dairy herd, he can soon sell the cows and stop buying concentrates, and use the money released elsewhere ; but the money sunk in his cowshed will be far more difficult to realise. It is for this reason that a depreciation allowance is charged in farm accounts on buildings and fixed equipment. This is not so much a wear-and-tear allowance as a way of gradually getting back the capital, out of profits, that has been put into the buildings, so as to use it again elsewhere. A realistic depreciation allowance is an essential piece of financial discipline in any farm plan requiring capital investment in fixed resources.

Sources of Fixed Capital. Money to purchase a farm may be borrowed by depositing the deeds with the lender as security. This is known as a mortgage, and the money can come from private individuals, banks, the Agricultural Mortgage Corporation, the Land Improvement Company, etc. New buildings may also be financed from these sources when carried out by the owner. (A tenant obviously cannot borrow on mortgage, as he has no title deeds to deposit.)

Sources of Working Capital. Loans for working capital can be of two kinds, medium- and short-term capital, depending upon the needs of the farmer. For machinery or equipment, the loan may be a medium-term one, spread over several years. For short-term, for seed purchases for instance, the loan may nominally be for a few months, until harvest perhaps. However, the need will arise next year, when another loan may be required in the same way. The differences between the two, medium- and short-term, are really only of degree, and they will be treated as essentially similar in this section.

The main source of such credit is the banks, through overdraft or formal loans. In the former case the farmer is given permission to draw more money than he has in his account, the amount depending upon the manager's estimate of his credit-worthiness and any security he may offer. He pays interest only on the amount actually over-drawn at any one time, rather than on the whole nominal value, as would be the case with a formal loan.

The other major source is merchant credit. Traders will supply seeds, etc., on credit, and charge interest for this service. There are drawbacks to this, in theory at least, as the farmer is then under obligation to the trader and the rate of interest may be high. But it is a simple system, and has worked surprisingly well over the years.

Hire purchase, especially for medium-term loans on equipment, is increasingly common, and is a form of merchant credit. Direct grants for part of the costs of specified improvement and guaranteed loans are available from government sources. Especially on small farms these can be a very important source of capital. The Agricultural Credit Corporation exists to underwrite loans on such farms for approved plans which will show an economic benefit.

Generally, sufficient credit is available to the prudent and established farmer. It is the newcomer lacking capital who finds it difficult to finance his ideas. But even here, there is a surprising number of ways in which a sound plan can be financed, if it is properly presented and supported by good estimates and figures.

COMBINATION OF ENTERPRISES

Having considered these various aspects of the three factors with which he has to work, the farmer must now organise his resources to give him the highest profit. To do this he must so juggle the combination of enterprises that the return to each factor tends to be equal. That is to say, he hopes to reach an organisation where any change in the balance of enterprises or resources would lead to less profit. This is known as the optimum solution, and is rather like the position of a traveller at the North Pole, where all directions are south. In the next section practical methods of implementing this concept are explained.

But before going on to consider them, there are two other aspects of organisation that require discussion. The first of these is size, both of farm and of enterprise.

Size of Farm. Taking the size of farm first, it was mentioned above that this will help to determine, to some degree, the type of enterprises that will be considered, as some are more suitable for large farms than small. Generally speaking, the larger the farm the larger the profit, because turnover, i.e. sales per annum, will be highest, and it is the volume of business that is most important in determining the profit.

A small farmer often overcomes this handicap of size by having intensive enterprises, that is enterprises with a high output per acre or per man. Examples are market garden crops. Again, as he is short of land, he can operate " processing " enterprises, such as pigs or poultry, where the only farm resources needed are a little land as a site for buildings, and labour to mind the stock, while all feed is purchased and brought on to the farm from elsewhere. In this way he virtually adds a second storey to his farm.

But when all has been said, the advantage will normally lie with the bigger farm, as the capital and labour investment per acre will usually be less, and it can more easily benefit from the economies of scale, that is the spreading of the cost of buildings or big equipment over more production. This assumes, of course, that the big and small farms are on similar soils and conditions. If one is comparing a small intensive farm in the Fens with a large hill farm, the turnover, and hence profit, is likely to be greater on the small farm. But this is an extreme case. The major drawback to a really large farm, apart from its cost, is the difficulty of supervision and management. It is on this point that many fail to reach their potential profit.

Size of Enterprise. When planning on any particular farm, the size of holding is normally given at the start. But there remains the question of size of individual enterprise on the holding. Should one have a number of small ones, providing a range of products which will spread the risk in face of failure or falling prices, or a few much larger ones? The answer to this will depend upon a concept of economic theory which is quite vital to successful farm planning—the concept of *Fixed and Variable Costs*.

Fixed and Variable Costs. Under this concept, the costs of production can be divided into two classes. The first consists of those that must be incurred if there is to be any production at all, but they will not increase as the volume of production is altered. These are known as the *fixed costs* and are: regular labour; machinery; rent, or landlord's costs; miscellaneous costs (telephone, etc., that cannot be allocated easily to enterprises). For instance, to harvest a crop of corn will require certain machinery—say a binder or combine. Once the machine is purchased, there is a wide range of production possible, without requiring a second machine; yet no production is possible (in practice at least) without the machine.

Taking the combine as an example, with a capacity of 150 acres per annum, the capital cost to the farm of harvesting machinery will be the same whether 70 acres or the full 150 acres are cut each year. If the volume is stepped up to 200 acres, either a second similar machine will be required or the original one can be replaced by one with a bigger capacity.

Hence, though these costs are called fixed costs, they are only fixed for ranges in volume of production. Really large alterations will require a change in the fixed costs, but even then these changes occur spasmodically, and not smoothly, with gradual increases in production.

The other class consists of those costs which will change directly as the volume or pattern of production changes, and are known as *variable* costs. Examples are the cost of concentrates changing with milk production, fertiliser costs with acres of a particular crop, or even with yield per acre—and so on.

As an enterprise gets larger, fuller use is made of the fixed costs, which as a result become less per unit of product. This is the reason why large-scale production is usually cheaper. But there are drawbacks, or else all enterprises would be large-scale ones. For example, large-scale enterprises may have to use much more expensive equipment, the costs of which may work out less per unit of product, but still the capital cost proves a barrier to many farmers. Again, really large enterprises require a high grade of management, and this may also be difficult to provide, especially if more than one such enterprise is to be operated by a single manager.

Diversification versus Specialisation. In deciding the question of size of enterprises, these points have to be weighed up. In favour of *diversification* is the spreading of risk, possibly also a reduction in working capital, for while the variable costs will be the same for large or small enterprises no really big fixed equipment may be necessary.

On the other hand, *specialisation* implies not only that once equipment has been bought it will be economically used, and hence total costs should be lower per unit of product; but also that management can concentrate on fewer lines and hence be more alive to new developments. With agricultural techniques changing as fast as they are today, this can be vital in the battle for the market.

Therefore it seems likely that reduction to three or four major enterprises, each of a reasonable size, may provide a practical compromise between the advantages of complete diversification and of specialisation, and might be termed *simplification*.

Profit. To get the biggest profit the farmer has to *organise* his resources of land, labour and capital so that the return to each is as high as possible. The plan he makes will be determined by the availability of resources and the productive enterprises open to him. Once the plan is made, he will have to ensure that it is carried out by exercising *control*. In the remaining sections various practical methods of attaining these objectives are described.

METHODS OF ORGANISATION

The first step in organisation is to make a list of the main resources that are to be used :

1. The acreage of the farm, including the amount that can be cultivated.
2. Any quota or husbandry restrictions, such as the biggest proportion of cereals that is acceptable, or the sugar beet quota that is available.
3. Capacity of buildings or facilities for livestock.
4. Regular labour and casual labour available, and for what tasks ; stockmen, tractor drivers, potato pickers, etc.
5. Total capital available to work the farm.

Next, a list of possible production enterprises is required giving the various kinds of livestock and crops that can be grown.

Planning. From this it is always possible to make up some sort of cropping and livestock plan on technical information alone, and then to cost out the various factors necessary, labour, feed, fertiliser, etc. A costing-out process of this sort is known as *budgeting* and such a budget is a *complete budget.* It is an essential preliminary before setting out to operate a farm organisation, because a plan, however sound technically, is of little use if it does not make the required profit. But here the first step is rather in the nature of an inspired guess.

There is another, more logical, method of obtaining guidance as to the type of plan to put together. This requires the planner to know *which enterprises give the highest return to his scarcest resource.* Suppose that land is the scarcest of the three factors, as it usually is in this country. Then one would plan to produce as much as possible of those enterprises that give the highest return to land—say potatoes or sugar beet, if they were on the list of " possibles ". But if too much of these crops were introduced into the plan, another resource —labour perhaps—would prove to be insufficient. Then the emphasis of the plan would be switched towards enterprises that might give lower returns to land, but which used much less labour, and so on until a complete organisation had been worked out.

There are mechanical and semi-mechanical methods for doing this, known as *programming*, which are beyond the scope of this section. But the basic idea underlying such methods can be used by anyone to arrive at a sound basis for his organisation. To do this it is necessary to write down the enterprises available in the order of their return to the resource believed to be the scarcest on the farm. If one mistakes the limiting factor, selecting land rather than labour, this will soon be made evident when the plan is drawn up, as one finds oneself with unused capacity.

These returns can be expressed in various forms : *Gross Income* (i.e. total sales) ; *Gross Output* (Gross Income less livestock purchases) ; *Net Output* (Gross Output less feed and seed purchases). Almost certainly the most useful is *Gross Profit* (sometimes called *Gross Margin*) which provides both a basis for planning and a shorthand for speedy budgeting. It is also the concept used in the computer programming techniques.

Gross Profit or Gross Margin. Simply, this is the *total output less variable costs.* For example, for *wheat* this might be, per acre :

Variable Cost.	£	Gross Income.	£
Seed	3	Sales 30 cwt @ 26*s*.	
Fertiliser	4	(inc. subsidy)	39
Sprays, etc.	1		
	8		
Gross Profit	31		
	£39		£39

To use this concept, the farmer must first split up his variable costs amongst the various enterprises, and deduct them from the relevant output to get the *gross margin* of each enterprise as in the example. The fixed costs (see p. 720) are not allocated but kept in a " pool " at first.

He must then consider various combinations of enterprises—so many acres of cereals, potatoes, etc., which he thinks he can manage with the labour machinery, etc., which comprise his fixed costs.

Once he has made such a plan, it is a simple matter to add up the gross margins and subtract the fixed costs to give the *net farm income* or profit of that plan. Another plan can then be considered, and its profit worked out in the same way until one is settled upon that will give the highest profit.

By using the gross margin as a measure of the return of each enterprise, an accurate indication is gained of the effect of expansion or contraction of any enterprise, and a great deal of laborious calculation of individual changes in variable costs is avoided.

The system is clearly suited to cash crops, but in addition the returns of grazing stock, such as dairy cows, can also be expressed in those terms. The gross profit is then related to the acreage of grass and other forage crops used, so that the gross profit per acre of dairy cows can be compared directly with that from cash crops.

PLANNING EXAMPLE

Data. 300 acre farm : 280 acres arable, 20 acres permanent grass, 30 acres sugar beet quota ; not more than 75 per cent in all cereals, and not more than 25 per cent in winter wheat.

Buildings etc. Suitable yard and parlour for up to 40 cows ; buildings for followers ; corn storage up to 180 tons ; combine of 220 acres capacity.

Labour. Accommodation for four men including the farmer; if necessary a fifth might be hired, living locally ; casual labour available for singling sugar beet but not for harvesting it.

Capital. £11,000 available from own resources and bank. Up to £3,000 more from merchant credit if necessary.

Possible enterprises.	Gross Margin per acre. £
Sugar beet	60
Wheat	35
Dairy cows	30 (2½ acres per cow and follower)
Barley	25
Oats	20
Beans	18
Clover	12

If details of labour requirement per unit of each enterprise at various times in the year are available, it is possible to plan *concurrently* on land and labour use, as is done by programming. But space prohibits any demonstration of this here, and for simplicity's sake the plan will be set out, first, in terms of returns to land, and then the labour requirement checked : any necessary adjustments to fit into the labour available will be made later.

Returns to Land.

	Gross Margin £
The best crop is sugar beet—30 acres @ £60	1,800
Next best, wheat, up to 70 acres @ £35	2,450
100 acres used.	4,250
Then dairy cows. Up to 40 + followers can be run in the buildings available. This means 40 × 2½ = 100 acres @ £30	3,000
200 acres used.	7,250
The remainder, 100 acres, can go into barley, because the upper limit for this crop (in view of the wheat acreage) is 140 acres.	
Barley 100 acres @ £25	2,500
Total	£9,750

Note that the last three crops listed as possible enterprises have not appeared at all. To introduce them would reduce the gross margin.

Labour Requirement. The labour requirement may be checked in one of several ways. The concept of *man-work units* may be used. A table of standard labour requirements is consulted and the figure for each enterprise multiplied by the number of acres or stock concerned. By adding up the results, the total man-work units can be found, and can be converted into the number of men needed by reference to the standard figure per man.

The system works well in organisations which have a steady labour demand throughout the year, as in livestock. With some crops such as cereals there is a peak demand, e.g. harvest, which must be met even if there is surplus labour throughout the rest of the year. In these cases it may be simpler to work out the number required at these peak months, depending upon the type of crop.

In our example there will be three peak periods ; sugar beet singling followed immediately by silage and hay making ; corn harvest ; sugar beet harvest and the cultivation and drilling of winter wheat.

For the first, casual labour is available for singling, and three men would be able to manage the silage and hay. For corn harvest, three men with a tanker combine could cope with 170 acres of cereals.

The third period, the autumn, presents the biggest problem. A sugar beet harvester requires three men to work efficiently, but can manage perhaps 50 acres or more in a season. At the same time there is the preparation of wheat land to be carried out. The answer is probably to get some early ploughing done after hay has been made, and then alternate periods of wheat land preparation and sugar beet harvesting until all the jobs are done. In this way, three men could manage the arable side. Without the harvester, however, a fourth man would be necessary or the acreage of beet must be reduced.

For livestock, provided the buildings and work routines were suitable, 40 cows + followers could be managed by a single man.

The next step would be to ensure that this plan could be fitted into a reasonable cropping sequence. It might be necessary to amend the acreages a little to fit into field sizes. In our case a 10-year rotation can be worked, though the proportion of wheat may have to be reduced a little, to fit in.

Fixed Costs. Finally, the fixed costs would be budgeted. Labour costs can be estimated from the number of men required. A short cut for both machinery and miscellaneous costs would be to use standard rates for farms of similar types and size. Failing that, they can be estimated from scratch, a tedious task ; where an existing farm is being replanned, the current rates of expenditure can be used, altered only where obviously necessary—in our case for the purchase of a sugar beet harvester. The rent would be the contracted rate.

To finish off our example, the final budget would be :

Fixed Costs.	£		£
Labour—4 men	2,200	Gross Margin	9,750
Machinery	1,900		
Rent and miscellaneous	1,500		
	5,600		
Farm Income or £14 per acre	4,150		
	£9,750		£9,750

Capital Requirement. Before finally accepting the plan, it is essential to check that sufficient capital is available. This will require a *capital budget.* There are two forms of such budgets, an annual one covering a whole year at a time ; or a consecutive series of budgets covering shorter periods, such as months or quarters, which give a *capital profile* over a given period.

Making an *annual* capital budget is really much the same as making a complete budget, except that certain items, such as machinery, are costed at full purchase price rather than on the basis of annual depreciation. Having produced a crop and livestock plan, the variable costs, rather than the gross profits, of each enterprise are entered in the budget, plus the fixed costs. This total is reduced by any sales that may be made during the year, as these receipts can be used to finance later expenditure. For instance, a milk cheque received in November can be used to pay for the concentrates used in December.

In such capital budgets, it is usual to assume that all bills are paid as soon as the items are received. Once the total capital requirement has been estimated, it is always open to the farmer to consider how much of this can be financed from merchant credit, i.e. by not paying bills at once.

When a new occupier is making a capital budget, additional items for living expenses during the first year, and tenant-right compensation, legal fees, etc., must also be taken into account.

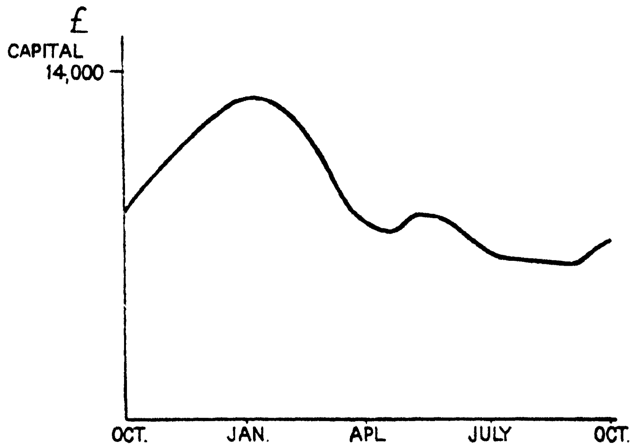
The *capital budget* for the farm organisation considered in the previous section would be as follows, assuming a Michaelmas start.

Fixed Costs.	£	**Contra Items.**	£
Labour	2,200	Milk (rec'd during 1st (year)	4,800
Machinery	5,000	Calves	300
Rent, etc.	1,500		
Livestock purchase	5,000		
			5,100
		Net amount required	13,370
Variable Costs.			
Wheat 70 acres @ £8	560		
Barley 100 acres @ £6	600		
Sugar beet 30 acres @ £27	810		
Dairy Cows 100 acres @ £28	2,800		
	£18,470		£18,470

This is within the restriction set out in the example (£11,000 + £3,000 merchant credit).

If a growing sugar beet crop had been taken over, an ingoing valuation would have to be paid, but the sales would be available during the year to defray further expenditure, so that the total requirement in such a case would probably have been somewhat less.

A *capital profile* would be based upon the same figures, but all expenses and receipts would be allocated to the relevant periods. The result might be as shown in the diagram below.



Capital profile—300 acres arable and dairy farm.

CHANGING THE PLAN

However well the initial planning has been done, there will always come a time when a change has to be considered. This may come at the very beginning, when it is found that the proposed plan will use too much labour or capital. It may come after one or two seasons, when the farmer may want to try new enterprises or change some of the originals which have proved disappointing.

In all these cases a budget should be made for the proposed change, to see what the financial effect will be. Unless a major upheaval is contemplated, such as the complete elimination of a dairy herd and its replacement by cash crops, a *partial budget* will give sufficient guidance as to the benefit or otherwise of the proposal.

The Partial Budget. A partial budget only considers the costs that will alter with the change being considered, leaving the bulk of the farm's costs and returns untouched, hence its name. To carry out such a budget, four questions have to be answered :

Costs.	*Returns.*
1. What extra costs will be incurred ?	3. What extra sales will be made ?
2. What present income will be foregone ?	4. What present costs will be saved ?

The balance between these two sides will show whether the proposal will result in a net increase in farm income or not.

If data about the farm are in gross profit terms, such a budget is a matter of minutes only, for the benefit will be the difference in gross profits, plus any change in the fixed costs. For instance, with a change of beans for barley, the gross profit or gross margin per acre for beans is £20, for barley £25. For every acre changed from barley to beans the loss is £5. If there is no saving in fixed costs, labour or machinery—and there does not seem to be any reason why there should be—the result would be a loss of income.

If data are not in gross profit form, then the full change in variable costs and sales will have to be set out, as below.

EXAMPLE OF A PARTIAL BUDGET

Extra costs.	£	£	**Extra sales.**	£	£
Beans			Beans		
Seed	6				
Fertilizer	2				
Spray	2				
	—	10	1 Ton @ £30 . .		30
Income foregone.			**Costs saved.**		
Barley			Barley		
27 cwt. @ 18s.			Seed. . . .	3	
(+ subsidy £8)		32	Fertilizer . . .	3	
			Sprays . . .	1	
				—	7
			Net loss. . .		5
		£42			£42

Clearly, having farm data in gross margin form means that these can be manipulated far more easily to estimate the effect of changes in plans, as well as providing guidance on the type of organisation to plan.

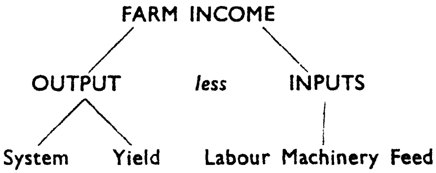
CONTROL—THE WHOLE FARM

Once the farm plan is under way, it is essential to keep a check on its progress to make certain that it is being carried out in the way intended. This is not just a question of a record of crop acreages and livestock numbers ; it involves also costs and returns to make sure that commodities are not being produced at a loss.

There is also the diagnostic side, particularly important where a farmer is not satisfied with the existing profits of his farm, and wishes to know where the weaknesses of his organisation lie. In such a case a new organisation may be called for, but it may only be a question of tightening up on the technical husbandry of the existing plan.

Normal Farm Accounts. The easiest starting point in most cases is the farm account which, in this country, has in any case to be kept for taxation purposes. Over the last two decades, several methods of analysing the ordinary farm trading account to gain management information have been published. Here it is sufficient to describe the general principles underlying such analyses.

The basic idea in nearly all cases is to compare certain *efficiency factors*, calculated from the accounts, with standards drawn from the accounts of a sample of similar farms. This can be termed the *comparative method.* These efficiency factors are generally the expression of an *input-output* relationship, e.g. value of production per £100 labour costs, and so on. The basic framework can be described by the following diagram.



Farm Income. This is virtually the same as trading profit, though in some cases corrections are made for credit costs, owner-occupancy and farmer's manual work. If income is found to be low, then either output is low for the type of farm, or the inputs, especially the fixed costs, are too high.

Output. This can be measured by *Gross Output* (Sales, corrected for changes in valuation, less livestock purchases) ; *Net Output* (Gross Output less seed and feeding stuff purchases) ; *Gross Margin* (Gross Output less variable costs). There are arguments in favour of all these. Generally speaking, the more mixed the farming system is, with arable crops and several types of livestock, the more useful Net Output or Gross Margin are, because a proportion of the output is based on " imported acres " in the form of concentrates grown elsewhere than on the farm.

System. If the output is low, it may be due to the system followed, in that not enough of the resources are devoted to high potential enterprises. Dairy cows have a higher output per acre than beef, and a switch in this direction might be indicated. Various methods of calculating a System Index are published.

Yield. Alternatively, the pattern of farming may be reasonable, but the yield (output per unit of land or stock) may be low. Unless the farm system is a very simple one, or the accounts more detailed than is normal, additional records may be required to discover which enterprises are at fault.

Inputs. These costs are usually expressed in terms of costs per unit of output—Labour per £100 Gross Output, or Net Output, etc. A poor result may of course be due to output being low. But failing this there may be too much labour for the enterprises kept. This can be tested in several ways already discussed on p. 723, but the commonest is through *man work units.*

Machinery. Again expressed as costs per £100 output. To diagnose the cause of a poor result is much more difficult, for depreciation and repair costs are to some degree complementary, new machines having high depreciation costs but low repair costs, and older machines the reverse. To correct a poor result may be even more difficult, though if it is due either to extravagance in investment or bad technical management, then a correction can be made in time.

Feed. The cost of feed per unit of livestock output is often the weakest link in a mixed farm, especially where large quantities of homegrown cereals are used and not recorded. More data than are usually available from a trading account are required to find the weak enterprises, and these are considered in the final section of this chapter.

This type of analysis is the least that any informed farmer should carry out as a control method. Unfortunately, while it will give a reasonable indication of weaknesses, it is usually unable to show which particular enterprises are weak, or how best to remedy any fault in fixed costs. Additionally, when corrections come to be considered and partial budgets used to determine the financial value of such changes, quite different data have to be used. Therefore there is an interest in finding a different form of account-keeping which would make control easier and supply better data for budgeting.

Special Accounts. In addition to the ordinary farm trading account and balance sheet, there are special accounts of a more detailed nature which can be very useful. These all require rather more records to be kept than is necessary for the normal accounts, referring especially to the allocation of certain costs to various sections of the farm.

Full Costs. In manufacturing industry large sums are spent in keeping full cost accounts, so that the manager knows exactly the cost of each unit of product. Many attempts have been made to apply the same ideas to agriculture, but on the whole they have not been successful. There are three main reasons for this. In the first place, the fixed costs in farming represent perhaps two-thirds of the total costs, and therefore much of the apparent result will depend upon the method whereby these costs are allocated to individual enterprises. If based upon labour use, as in some cases, then one set of answers will be produced. If on capital, or even output, quite different ones. Secondly, a complex recording scheme is required to find out just where and when these fixed costs have been used, so that the sheer cost of running such accounts is high, and most agricultural businesses are not really large enough to carry such expenses. Finally, the management information derived from such accounts is not always useful. Because fixed costs represent so large a proportion of the total, reduction of output in one enterprise, or the elimination of an enterprise, may not affect costs very much if fixed costs are untouched —as is often the case.

Enterprise Costs. A variation of complete full costs is to keep the same sort of data for one or two major enterprises on a farm. At first sight this seems a more feasible plan and certainly involves less work, for it is only necessary to record the use of fixed costs, labour and machinery, for these enterprises, rather than for the whole farm. But to make the scheme workable, certain standards have to be used, e.g. the cost of tractors per hour. This introduces an arbitrary element into what sets out to be an entirely objective record. More important, an arbitrary allowance for farm overheads may also affect the result. Then, there is no check that the recording has been done correctly, for the account does not tie up to any other accounts for the farm if as is usual, it is being carried out for only part of the farm organisation.

None the less, such enterprise accounts can be most useful, especially where livestock are concerned, for here they force the farmer to recognise the amount of feeding stuffs being used. However, information just as valuable could be achieved by simple feed recording, without going to the bother of allocating fixed costs at standard charges.

Intermediate Accounts. It should be possible to gain the advantages of enterprise costings without the disadvantages, by reorganising the farm accounts on the basis of fixed and variable costs. If the farm records were so organised as to show the allocation of variable costs—feed, seed, fertiliser etc.—to the various enterprises, and the value of sales were similarly allocated, then the gross profit or gross margin of each enterprise could be calculated. The fixed costs would be shown separately and would have to be defrayed before the profit were found. (For definition of gross margin, see p. 722.)

ANALYSIS

Enterprises. The pattern of analysis is much the same as that followed with the normal trading account. However, after looking at total output, attention is directed to the individual enterprises. It is a simple matter to compare the gross margin per acre of each enterprise with an acceptable standard, derived from the local advisers or from neighbours. If the result for any enterprise is low, the causes should be investigated, as described in the next section.

Fixed Costs. The fixed costs are much less amenable to alteration in themselves than the gross margins, and most corrections will take the form of altering the pattern of output rather than altering the fixed costs. Nevertheless, it is useful to have a quick check on the relationship between the fixed costs and output, as in the comparative method. Here the fixed costs can be expressed as a percentage of the total gross margin of the farm. The proportions will vary with the area and type of farm, but a very general rate has been found to be: Labour, $\frac{1}{3}$; Machinery, $\frac{1}{5}$; Others, 15 per cent of gross margin.

Under this system, any weak link amongst productive enterprises is located more readily. Disproportionate fixed costs are shown up, but here there are no particular advantages over the straight comparative method. More important is the fact that the data are in the form necessary not only to guide any reorganisation that may have to follow, especially to make better use of fixed costs, but also for budgeting such changes as are considered.

From what has been said it should now be clear that the first stage in controlling the farm organisation is to use the accounts to provide warning that all is not well. Various systems can be followed, the simplest being an analysis of the existing form of trading account as used for taxation returns. This has to be supplemented by additional information about individual enterprises. This may be done either as a separate operation, or by keeping the original accounts in the appropriate form.

CONTROL OF ENTERPRISES

The following sections are based upon the supposition that some form of analysis has been undertaken and that this has disclosed some weakness in the organisation. Depending upon the system of analysis adopted and the records kept, the farmer may also know in which enterprise or fixed cost this weakness lies. In all that follows, attention is mainly directed towards discovering the cause of such faults. In most cases the remedy will lie within the province of technical husbandry, and will not be discussed.

Crops. In almost all cases the reason for a low output from a crop enterprise will be yield rather than excessive inputs. The financial yield is made up of the physical yield × the price per unit. With some high value crops this fact may be vital; a poorish physical yield may be more than compensated for by high prices. In these cases, marketing may be just as important as efficient technical production. This is so with many horticultural crops, where price received will depend upon many marketing factors, the state of demand, weather, other supplies, alternative products, presentation and packaging etc. But with most farm crops low output and low physical yield go together, so that it is essential to determine the cause of the latter, which will be a matter of husbandry. Therefore only such records should be kept as are necessary to help in such diagnosis. A field diary, in which a record of variable costs and yield is kept, together with a note of any special treatments, such as spraying, with all relevant technical information, is often of great service here.

Grazing Stock. With grazing stock, low output may be due to (i) Low physical or financial yield (mainly summer milk or small eggs are examples of the latter). (ii) Excessive concentrate feeding. (iii) Understocking of forage acreage. (iv) Too great a proportion of followers retained in dairy herds ; followers have a much lower output both per acre and per head than productive dairy cows.

Again enterprise records are necessary to determine which of these causes is operating. The field diary mentioned above can be expanded to take in the forage acreage, and a record kept of its use between livestock enterprises. In addition, a concentrate feed record is necessary, especially where home-grown cereals are used, and where there is more than one livestock enterprise.

Low yields can be checked from sales records, and excessive feeding from the feed record. Understocking can be checked from technical knowledge, or by the use of *livestock units*. These are a conversion factor, whereby all types of grazing stock can be reduced to a single common unit—equivalent to a medium-yielding dairy cow. By expressing all grazing stock on the farm in these terms and dividing the forage acreage by this total, the factor of *forage acres per livestock unit* is calculated. The desirable figure will vary with the district, but a common one for lowland farms on fair soil is 1·5 acres per livestock unit.

Pigs and Poultry. Here there are no complications of forage acres and livestock density. Poor returns will be due to a low output from low yields or excessive concentrate feeding. But as these stock can be virtually divorced from the rest of the farm and they have a very high rate of turnover compared with other farm enterprises, more detailed recording is probably justified if the enterprise is of any size. The following records would be desirable on the majority of pig or poultry enterprises where the annual gross output exceeds £2,500.

Pigs. If both breeding and fattening are carried out on the same farm, they should be regarded as separate enterprises and the use of feeding stuffs recorded separately for each. The breeding herd should have litter records to show the average number of pigs farrowed and weaned per litter, the average number of litters per sow per year and the average weight per weaner. In addition, the total weight of food fed to the herd in a year can be divided by the number of weaners to give the weight and cost of food per weaner. For the fattening herd a record of all liveweight gained should be kept, by weighing all pigs on entry and despatch from the herd. The conversion factor, food per pound liveweight increase, can be calculated by dividing the food fed, and its cost, by the liveweight gain in the period. If pigs are being marketed to bacon, a record of gradings is also important.

Poultry. Simple egg yield over a year is really not sufficient. A calculation of the " percentage lay " should be done weekly, by taking the number of eggs laid as a percentage of the birds in the house. Once the rate falls below 60 per cent the margin left for profit must be getting very small. Food per bird per week should also be calculated and compared with accepted husbandry levels, as it is extremely easy to go astray in this type of intensive enterprise. One further aspect, at the end of the year, or when the flock is culled, deserves attention, and that is the difference between the value of the birds at point of lay and their sale value at the end. This depreciation can often be as much as 10*s.*–15*s.* per bird, and may represent the gross margin on up to two-thirds of the bird's production. Therefore every effort should be made to close this gap, either by rearing more cheaply or attempting to get a better cull price.

The table bird industry is so very competitive that margins are very near the minimum, so there is little room for error. It should be possible to cost the food and sales of each batch with little difficulty. This should be done to keep a constant check on the profitability of the enterprise. With margins so low, to wait even two months before finding out that things are not going according to plan could be a disaster.

Summary. Keeping a check on crops presents little difficulty as physical yield, and in some cases prices, are all that is required, and the time element is not pressing. Once a year checks are sufficient.

For grazing stock, while continuous recording of feed is necessary, together with any sales, it is probably only with dairy cows that checks need to be made more often than once a year. Even with cows a quarterly check of feed use and milk output is probably sufficient.

With pigs and poultry, while there are really only two factors involved, concentrate feeding and production, yet because of the high rate of output constant checks are necessary, especially in the case of table birds, where costings should be on a batch rather than total flock basis.

CONTROL OF FIXED COSTS

In the discussion on organisation, the intractable nature of the fixed costs, especially machinery, was noted. As a result, no special records are generally necessary, for control purposes, for a farmer is hardly likely to have more men or tractors than he thought. Generally, the total cost of each of these factors, as recorded in the trading account, is the only financial record necessary.

However, there are two sets of records of a quasi-physical nature than can be kept to aid management, especially on really big farms : these are timesheets for labour, and log-books for tractors and large equipment.

Timesheets. These are often used to provide a basis for wage-payment. If the workers get in the habit of recording their tasks accurately, managers of large-scale farms often gain valuable insight into the amount of really productive work compared with the total hours worked, and can adjust their methods accordingly. If full-cost accounts are being kept, such records are essential, but the value of such accounts has already been discussed.

Log-books. These should be kept for all valuable machinery, not so much as a guide to the work that is done (though this is sometimes of great interest), but mainly to see that routine maintenance is being observed, and as a check on the rate of repairs. Again in full cost accounts they are essential.

Labour Costs. Though it has been stressed that the fixed costs are intractable, labour is relatively the easiest one to manipulate. It has been shown in the budgeting section that changes in organisation will not result in changes in labour costs unless the number of men is actually reduced. When a farmer is considering the possibility of reducing labour costs, he must first decide what are the enterprises or operations which cause him to keep his current labour force, by virtue of the peak labour demand. Once he has decided this, he has two courses open to him :

1. To eliminate or reduce the enterprise, thereby reducing demand. For this to be economically worthwhile, the value of wages saved must be greater than the loss in total gross margin.

2. To alter the techniques in the enterprises, so as to reduce labour. This normally means mechanisation, and here again the cost of mechanisation must obviously be less than the wages saved.

But on occasion a change in technique means doing the same task in a different way. Perhaps reorganising the lay-out of buildings or equipment, or rearranging men's tasks. It is here that *work-study* can play a vital part in examining current routines and pointing the way to better ones, that will reduce labour per unit of output. An outstanding example has been the use of work-study in milking routines.

A third type of alteration may be to vary the period in which certain tasks are performed, so as to reduce labour demand in bottleneck periods. For instance, variations of drilling dates may serve to spread sugar-beet singling, and so allow fewer men to cover the same acreage.

SUMMARY

Farm Management means first of all planning the use of the farmer's resources—land, labour and capital—to give him the highest profit. A useful aid to this is the division of costs into two categories, fixed and variable. He should plan his farm so that as much of it as possible is devoted to those enterprises which give a high return (after defraying their respective variable costs) to whichever factor is scarcest. This means that on a small farm the plan should concentrate on those products that have a high return to land, whereas on a larger one, more products that give a lower return to land but require less labour can be considered.

Once the plan has been decided upon, it is essential to exercise control over it. The simplest way to do this is through the ordinary farm account, but usually this has to be supplemented with additional data, except in the simplest cases. As production continues, the plan should be constantly tested, to see whether improvements cannot be made.

But when all is said and done, the best plan will be unsuccessful if it is not supported by sound husbandry. The idea that a few abstruse calculations are sufficient to put a farmer on the road to success is a mistaken one. Farm Management is the economic expression of technical husbandry, and the two parts are vital to the sound working of a farm.

APPENDIX I

SOWING AND YIELD DATA FOR CROPS

Crop.	Time of Sowing.	Time of Harvest.	Seed Rate per Acre.	Weight of 1 Bushel of Seed.	Yield per Acre (cwt). Grain.	Yield per Acre (cwt). Straw or Feed.
WHEAT :						
Winter varieties	Oct.–Jan.	Aug.–Sept.	1–1¾ cwt.	63 lb.	25–40	30
Spring varieties	Feb.–April	Sept.	1¾–2¼ cwt.		20–35	
BARLEY :						
Winter varieties	Oct.–Dec.	Aug.	1–1½ cwt.	56 lb.	20–40	23
Spring varieties	Feb.–March	Sept.	1–1¼ cwt.			
OATS :						
Winter varieties	Oct.–Nov.	July–Aug.	1–1½ cwt.	42 lb.	15–35	27
Spring varieties	Feb.–April	Aug.–Sept.	1½–2 cwt.			
RYE :						
Winter varieties	Sept.–Oct.	July–Aug.	1–1½ cwt.	54 lb.	16–20	35
Spring varieties	Feb.–March					
For feeding off	Aug.–Sept.	April–June	1½–2 cwt.	54 lb.	—	—
BEANS :						
Winter varieties	Oct.	Aug.	1½–2 cwt.	63–66 lb.	18–30	25
Spring varieties	Feb.–March	Sept.	2–2½ cwt.		15–25	
PEAS (Field)	Feb.–March	Aug.	1¼–1¾ cwt.	63–65 lb.	17	20
VETCHES (= Tares) [1]						
Winter varieties	Oct.	July	1¼–2 cwt.	64 lb.	14–17	25
Spring varieties	Feb.–March					
SAINFOIN : [2]						
Giant	late March and April	July	4 bushels (unmilled)	30 lb. (unmilled)	8 (unmilled)	—
Common			½ cwt. (milled)	60 lb. (milled)		
LUPINS	April	Aug.	½–1 cwt.	62 lb.	11–16	—
CRIMSON CLOVER [3]	Sept.–Oct.	Late spring and early autumn	20 lb.	60 lb.	4	—
LUCERNE [4]	April	June onwards	12–16 lb.	60–62 lb.	4	8–15 tons (as a green crop) 2–3 tons (as a hay crop)
TREFOIL [5]	April–May	June onwards	15 lb.	60 lb.	4–4½	10 tons (green crop)
RED CLOVER [6], [7] (as a seed crop)	March–April	June (feed) Sept. (seed)	16 lb.	65 lb.	4–5	2 tons (as hay)
MANGEL [8]	Late April and early May	Nov.–Dec.	7–10 lb.	21 lb.	10	25 tons (feed)
SUGAR BEET [9]	Mid-April to early May	Nov.–Dec.	15 lb.	20 lb.	10	8–15 tons (roots) 5–10 tons (top)
MARROW STEM KALE	April–June	Nov.–Dec.	4 lb.	54 lb.	7	15–25 tons (feed)
THOUSAND HEADED KALE	March to early June	Nov.–Feb.	4 lb.	54 lb.	7	12–20 tons (feed)
RAPE (= Coleseed)	Throughout Spring and Summer	October to April according to sowing-time	3–4 lb. (drilled) 6–8 lb. (broadcast)	50 lb.	10–15	10 tons (feed)
CABBAGE [10]	March	Nov.–Dec.	4 lb.	53 lb.	10	20 tons (feed)
KOHL RABI [11]	March–April	Oct.–Nov.	4–5 lb.	54 lb.	7	20 tons (feed)
TURNIP [12]	July	Oct.	3–4 lb.	50 lb.	8	15–25 tons (feed)
SWEDE [12]	June	Nov.	3–4 lb.	50 lb.	7	15–25 tons (feed)
MUSTARD [13]	April	Aug.–Sept.	12–14 lb.	54 lb.	6–12	—
CARROT	April–May	Oct.–Dec.	1½–4 lb.	30 lb.	—	10–20 tons
BUCKWHEAT	Late May	Sept.	¾–1 cwt.	50 lb.	10–15	—
LINSEED (for seed)	Late March and April	Aug.	½–¾ cwt.	52 lb.	7–10	20–30 cwt. (straw)
POTATOES [14]	March and April	Late June to Oct.	15–20 cwt.	54 lb.	—	8–15 tons
MAIZE	Mid-May	Sept.	30–40 lb.	60 lb.	—	20–25 tons (feed)

Appendix I

SOWING AND YIELD DATA FOR CROPS

NOTES TO TABLE ON PREVIOUS PAGES

[1] The data given are for vetches grown for seed. Vetches may be grown for hay: they give about 30 cwt. per acre.

[2] The straw from a seed crop of sainfoin is worthless for feed, being entirely hard stems. Sainfoin may be sown for hay, giving 30–40 cwt. of hay per acre. See also Note 7.

[3] Crimson clover is usually sown in autumn on a stubble. See also Note 7.

[4] Planting may take place any time from April to August. See also Note 7.

[5] Trefoil is usually sown under a corn crop. See Note 7. Sometimes seed is sown in the cosh (pod), at 50 lb. per acre.

[6] Both types of red clover—broad-leaved and late flowering—are usually mixed with grasses when sown for feed or hay. Broad-leaved clover may be cut for hay or heavily sheeped in May and then left for seed. But the late-flowering type, if first cut for hay, is so late in flowering that little seed is set. It may, however, be lightly sheeped in April (not later) and then left for seed.

[7] The order of availability for grazing of the common leguminous fodder crops is usually: winter vetches (first), trefoil, lucerne, broad-leaved red clover and sainfoin, late-flowering red clover, spring vetches.

[8] For a seed crop, sowing is in July, in rows about 12 in. apart and at 20 lb. per acre. The plants are lifted and planted out in the same field in February or early March in rows at 28 in. and at 12 in. in the row. Alternatively seed may be sown in July in the manner adopted for ordinary sowings of mangel and left to grow to seed. It is cut by hand in September.

[9] One acre of beet tops will feed 100 ewes for one week, there being available also a suitable grass run.

[10] The data here are for a crop treated like a root crop for a variety such as the Ox-drumhead. For transplanting, 1–2 lb. of seed sown in 2 square rods is sufficient to plant 1 acre.

[11] Kohl Rabi may be transplanted similarly to cabbage (see Note 10).

[12] In the North and in Scotland turnips and swedes are sown about a month earlier than the dates given here, which are for the eastern and southern counties of England. The yield of both crops is largely determined by rainfall, being light in the drier areas. One acre of good turnips will keep 100 ewes for 2–3 weeks.

[13] The data here are for white mustard but apply approximately to brown mustard also. White mustard is often grown in the southern and eastern counties for folding. About 20 lb. of seed is drilled or broadcast per acre and the crop may be eaten off in 6–8 weeks after sowing, which may take place at any time between April and August.

[14] The treatment of potatoes varies widely as between districts and as between early, second, and maincrop varieties. The data here given are merely representative.

Appendix II

THE SEEDS ACT, 1920

THE purpose of The Seeds Act, 1920, is to protect the farmer and horticulturalist against knowingly purchasing and sowing seeds which are of low vitality and contaminated with weed seeds. It applies to almost all farm seeds and many garden and forest tree seeds : its requirements affect the sale of seeds from farmer to farmer as well as from seedsman to farmer. The Seeds Regulations, 1961, differ materially from previous Regulations : their main provisions are set out below.

Particulars which must be given in all cases include : (1) the name and address of the seller ; (2) a statement that the seeds have been tested in accordance with the provisions of the Seeds Act, 1920 ; (3) the kind of seed ; (4) Where the seeds have been treated with a liquid or powder to control pests or diseases or have been fumigated, pelleted or rubbed, (*a*) a statement whether the particulars of purity and germination are based on tests made before or after the treatment, (*b*) in the cases of treated seeds, the nature or the proprietary name of the liquid or powder, (*c*) in the case of seeds which have been fumigated, the nature or proprietary name of the fumigant and the purpose for which it has been applied, (*d*) in the case of pelleted seeds, the nature or proprietary name of the pelleting material and the purpose for which it has been applied, (*e*) where the seeds are hybrid seeds, a statement indicating that the plants grown from them cannot be relied upon to yield seed with the same characteristics, (*f*) where the seeds comprise a mixture, a statement to that effect and such particulars in respect of each constituent as would be required if that constituent alone was sold, together with a statement of the proportion expressed as a percentage by weight of each constituent present : provided that where the mixture was made during the period of 12 months which expired on 31st July last previous to the date of sale, the particulars relating to purity, injurious weeds and other weeds may be given in respect of the mixture as a whole. Also where the mixture is one of seeds derived from plants which have been grown together it shall be sufficient to state that fact and to give particulars in respect of the mixture as a whole.

In addition, further particulars have to be given according to the kind of seed, and the more important of these particulars are summarised in the accompanying Table (garden seeds and forest tree seeds omitted).

The Official Seed Testing Station for England and Wales is situated in Huntingdon Road, Cambridge. Farmers can have samples of seed tested there at a cost of 4*s*. per sample, provided an undertaking is given that the test is not required in connexion with a declaration for sale. The minimum weights of samples of seed for testing are given in the last column of the Table. *Seed Potatoes* Particulars to be declared are : (1) Name and address of the seller ; (2) Class, i.e. Certified (Scotch), Certified (Northern Ireland), Certified (Republic of Ireland), Certified (English), Certified (Welsh), Certified (Isle of Man) ; Uncertified (English once-grown), Uncertified (Welsh once-grown), Uncertified (Scotch), Uncertified (English) or Uncertified (Welsh) ; (3) In the case of certified seed potatoes, the reference letters and number of the relative certificate ; (4) Variety ; (5) Size and dressing ; (6) Where the seed potatoes have been treated with a liquid or powder to control pests or diseases, or have been otherwise treated for that purpose, or have been treated with a sprout depressant, a statement of (i) the nature or the proprietary name of the liquid or powder, or (ii) the nature of the other treatment to control pests or diseases and the purpose for which it has been applied, or (iii) the fact that the seed potatoes have been treated with a sprout depressant, and the nature or the proprietary name thereof, as the case may be.

NOTES TO FOLLOWING TABLE

(*a*) It is sufficient to specify either the variety of the seeds or to say "variety not specified". In all other cases particulars must be given of *either* (i) variety, (ii) type, (iii) variety and type *or* the words "variety and type not specified".

(*b*) The name of the country in which the seeds were grown, or a statement that the country in which the seeds were grown is not known, must normally be stated. For cereals, a similar statement must be given or, alternatively, in the case of seeds grown in the United Kingdom, a statement to that effect. For root and vegetable seeds, provided the seeds are not stated to be "certified" or "Field Approved", these particulars need not be given unless demanded by the purchaser of the seeds.

(*c*) If the percentage purity is not less than the prescribed declarable minimum, a statement to that effect, disclosing the minimum percentage prescribed, is sufficient.

(*d*) Injurious weeds : for herbage and field seeds the name and number of seeds, as ascertained on a purity test, of any of the injurious weeds of which more than one seed was so ascertained (the seeds of docks and sorrels are regarded as seeds of the same kind) must be stated. For cereal seeds the name and number of seeds of any of the injurious weeds in a sample of 8 oz. as ascertained on a test made at an official or licensed seed testing station must be given.

The Injurious weeds for the purpose of the Act are

Wild Oat (*Avena fatua* L. and *A. ludoviciana* Durieu)
Dodder (*Cuscuta* spp.)
Docks and Sorrels (*Rumex* spp.)
Black Grass (*Alopecurus myosuroides* Huds.)
Couch Grass (*Agropyron repens* (L.) Beauv.)

(*e*) Either the percentage of germination of the seeds may be given or, if such percentage is not less than the prescribed minimum, a statement to that effect, disclosing the minimum percentage prescribed.

Kind of Seed.	Variety and Type.	Origin.	Purity.		Injurious Weed Seeds Present.	% Weed Seeds if over 0·5%	Germination.		Hard Seeds % by Number.	Minimum Quantity needed for testing (oz.).
			% by Weight.	Declarable Minimum %			% by Number.	Declarable Minimum %.		
Grass and Clover Seeds										
Perennial ryegrass	X	X	X	—	X	X	X	—	—	2
Short rotation ryegrass	X	X	X	—	X	X	X	—	—	2
Meadow fescue	X	X	X	—	X	X	X	—	—	2
Red fescue	X	X	X	—	X	X	X	—	—	2
Timothy	X	X	X	—	X	X	X	—	—	2
Cocksfoot	X	X	X	—	X	X	X	—	—	2
Red clover	X	X	X	—	X	X	X	—	X	2
Alsike clover	X	X	X	—	X	X	X	—	X	2
White clover	X	X	X	—	X	X	X	—	X	2
Crimson clover	X	X	X	—	X	X	X	—	X	4
Sweet clover	X	X	X	—	X	X	X	—	X	2
Suckling clover	X	X	X	—	X	X	X	—	X	2
Lucerne	X	X	X	—	X	X	X	—	X	2
Sainfoin	X	X	X	—	X	X	X	—	X	8
Trefoil	X	X	X	—	X	X	X	—	X	2
Kidney Vetch	X	X	X	—	X	X	X	—	X	4
Birdsfoot trefoil	X	X	X	—	X	X	X	—	X	2
Cereal seeds										
Wheat	X (*a*)	X	X (*c*)	99	X (*d*)	X	X (*e*)	90	—	8
Barley	X (*a*)	X	X (*c*)	99	X (*d*)	X	X (*e*)	90	—	8
Oats	X (*a*)	X	X (*c*)	99	X (*d*)	X	X (*e*)	85	—	8
Rye	X	X	X (*c*)	99	X (*d*)	X	X (*e*)	80	—	8
Maize (excluding sweet corn)	X	X	X (*c*)	99	X (*d*)	X	X (*e*)	75	—	8
Field Seeds										
Flax and Linseed	X (*d*)	X	X	—	X	X	X	—	—	4
Tares and vetches	X	X	X	—	X	X	X	—	—	8
Lupin	X	X	X	—	X	X	X	—	—	8
Sunflower	X	X	X	—			X	—	—	8
Root and Vegetable Seeds										
Sugar Beet	X (*a*)	X (*b*)	X (*c*)	97	—	—	X (*e*)	70 (of clusters)	—	8
Fodder Beet	X	X (*b*)	X (*c*)	97	—	—	X (*e*)	70 ,, ,,	—	8
Mangel	X	X (*b*)	X (*c*)	97	—	—	X (*e*)	70 ,, ,,	—	8
Beans (field)	X	X (*b*)	X (*c*)	98	—	—	X (*e*)	90	—	16
Peas (field)	X	X (*b*)	X (*c*)	99	—	—	X (*e*)	80	—	8
Swede	X	X (*b*)	X (*c*)	98	—	—	X (*e*)	80	—	4
Turnip	X	X (*b*)	X (*c*)	98	—	—	X (*e*)	80	—	4
Rape	X	X (*b*)	X (*c*)	98	—	—	X (*e*)	85	—	4
Kale	X	X (*b*)	X (*c*)	98	—	—	X (*e*)	75	—	4

Appendix III

RESIDUAL VALUES OF FERTILISERS

* *Unit value (22·4 lb.) per ton of fertiliser*

	After One Crop.	After Two Crops.	After Three Crops.	After Four Crops.
	s. d.	s. d.	s. d.	s. d.
Nitrogen (N)				
(*a*) Inorganic and dried blood .	nil	nil	nil	nil
(*b*) Organic nitrogen (excluding dried blood) . . .	6 0	3 0	nil	nil
Phosphoric acid				
(*c*) P_2O_5 sol. in water or in citric acid	6 8	3 4	1 8	nil
(*d*) P_2O_5 insol. in water or of unspecified solubility . .	3 4	1 8	10	nil
Basic slag				
(*e*) P_2O_5 sol. in citric acid .	6 8	3 4	1 8	nil
(*f*) P_2O_5 insol. in citric acid .	3 4	1 8	10	nil
Bone products				
(*g*) Total P_2O_5 in bone products	5 0	2 6	1 3	nil
Potash				
(*h*) Total K_2O . . .	3 6	1 9	nil	nil

Quoted from Statutory Instrument, 1959, No. 496, H.M.S.O. The Agricultural (Calculation of Value for Compensation) Regulations, 1959.

* This unit value must not be confused with the fertiliser unit 1/100 cwt. or 1·12 lb., now being extensively used in advisory work.

Appendix IV

BULL AND BOAR LICENSING REGULATIONS (ENGLAND AND WALES)

The licensing of bulls and boars is carried out under the Improvement of Livestock (Licensing of Bulls) Act, 1931, as amended and applied to boars by the Agriculture (Miscellaneous Provisions) Act, 1944, and regulations made under the Acts. The regulations current from 1st October, 1956, are the Licensing of Bulls (England and Wales) Regulations, 1956, and the Licensing of Boars (England and Wales) Regulations, 1956.

There are three types of licence for bulls—

(1) A BEEF BULL LICENCE restricted to bulls which are registered, and are duly marked or otherwise identifiable as being so registered, in the pedigree register of one of the approved beef cattle breeding societies. The approved breeds for this purpose are: Aberdeen Angus, Belted Galloway, Hereford, Highland, Lincoln Red Shorthorn, Red Poll, Shorthorn, South Devon, Sussex and Welsh Black.

(2) A DAIRY BULL LICENCE for which a bull may now qualify in one of three ways:

  (*a*) If the bull's dam and the dam of its sire have each given a qualifying yield in any lactation;

  (*b*) If the bull's dam has given a qualifying yield in any lactation and the average of the first calf yields of all daughters—there must be at least 10 daughters—of the bull's sire is not less than the appropriate qualifying yield;

  (*c*) The average of the first calf yields of the bull's own daughters—there must be at least 10 daughters—is not less than the appropriate qualifying yield.

(3) A GENERAL CLASS BULL LICENCE for bulls that are not eligible for either (1) or (2) but are otherwise suitable to be licensed.

The applicant for a Dairy Bull Licence has to establish to the satisfaction of the Minister that the dam of the bull in respect of which application is made, and the dam of the bull's sire, have each attained such standard of milk yield with butterfat content as is specified.

The standard is the production, in a lactation period of 305 consecutive days following calving, of a milk yield that is not less than the quantity specified in the following table in relation to the breed and the calving in question and contains a quantity of butterfat that is not less than the quantity so specified and is not less than the percentage so specified of the milk yield. The calving shall be such one of those specified in the table as the applicant may select and different calvings may be chosen for different ancestors.

STANDARDS FOR DAIRY BULL LICENCE

Breed.	Minimum Yield of Butterfat and Milk.						Minimum Percentage of Butterfat Content.
	With First Calf.		With Second Calf.		With a Subsequent Calf.		
	Milk (lb.)	Fat (lb.)	Milk (lb.)	Fat (lb.)	Milk (lb.)	Fat (lb.)	
Ayrshire	6,500	247	7,500	285	9,000	342	3·8
British Friesian British Canadian Holstein-Friesian and Red and White Friesian	7,000	250	8,000	280	9,500	333	3·5
British White	5,500	209	6,500	247	7,500	285	3·8
Dairy Shorthorn Lincoln Red Shorthorn and Northern Dairy Shorthorn	6,000	225	7,000	262	8,000	300	3·5
Dexter	4,000	160	5,000	200	6,000	240	4·0
Guernsey	6,500	310	7,500	355	8,500	400	4·25
Jersey	6,000	300	7,000	350	8,000	400	4·5
Kerry	5,500	203	6,500	240	7,500	277	3·7
Red Poll	6,000	225	7,000	262	8,000	300	3·5
South Devon	5,500	220	6,500	260	7,500	300	4·0
Welsh Black	5,000	200	6,000	240	7,000	280	4·0

VARIETIES OF CROP PLANTS

Crop varieties are continually changing; they are also being produced in large numbers. Some of the varieties are good, many have little to recommend them. For many years the National Institute of Agricultural Botany has been testing crop varieties in field trials at many centres throughout the country. It issues every year a number of Farmers' Leaflets to help farmers choose between the crop varieties available. For cereals, potatoes and sugar beet the Institute issues Recommended Lists; for field beans, swedes, maize, lucerne and grasses it issues Descriptive Lists.

The information given below is taken, by permission of the Council and Director of the N.I.A.B., from the literature published by the Institute for the harvest year 1961.

The varieties are classified as follows:

G Recommended for **General use.**
S Recommended for **Special use.**
O Becoming Outclassed by other recommended varieties.
When **G** or **S** are followed by **(N)** this denotes the **New Recommendation** of a variety on which further trials are still in progress.

High figures in the tables indicate that the variety shows the character to a high degree.

WHEAT

RECOMMENDED LIST OF WINTER WHEATS 1961

Varieties are in order of expected yields under average conditions.	Professeur Marchal.	Cappelle-Desprez.	Flamingo.	Minister.	Hybrid 46.	Elite Lepeuple.	Banco.	N.59.	Dominator.	Milfast.
	G(N)	G	G(N)	O	G	G(N)	O	S	O	O
Agricultural Characters:										
Standing power	6½	7	7	7	8	6½	6	6	6	7
Shortness of straw	6½	7	4	6	7	6	4	3½	6	6½
Resistance to shedding	5	7	7	5	6	8	6	7	8	7
Resistance to sprouting	6	7	3	2	5	6	6	6	7	7
Resistance to yellow rust	7	5	5	9	9	7	5	8	7½	5
Resistance to loose smut	9	2	6	7	2	7	9	4	9	7
Resistance to mildew	6	7	7	6	7	7½	8	7	7½	7
Earliness of ripening	8	8	8	8	7½	7½	4	7	9	9
Suitability for late sowing (early February)	6	7	4	7	7	8	2	8	7	7
Quality of Grain:										
Milling quality	5	5	3	6	4	9	7	7	9	9
Bread-making quality	4	5	3	5	4	7	7	4	7	9
Biscuit-making quality	6	4	8	7	6	4	2	3	4	2

Professeur Marchal **G(N)**	Very heavy yielding with short fairly stiff straw. "Hard" type grain of moderate milling quality.	White chaff, red grain. (Hybride du Joncquois × Prof. Delos) × (Bastard II × Prof. Delos). Gembloux, Belgium.
Cappelle-Desprez **G**	Very heavy yielding, with very short stiff straw, suitable for a wide range of conditions. Formerly resistant to loose smut but many stocks now infected. Has good resistance to eyespot. Of moderate milling and bread-making quality.	White chaff, red grain. Hybride du Joncquois × Vilmorin 27. Desprez, France.
Flamingo **G(N)**	Very heavy yielding with fairly long but stiff straw. A biscuit-making variety with white grain, liable to sprout in a wet harvest but rather less so than Minister. Present stocks contain varying amounts of red grain, and seed should only be bought from a reliable source.	White chaff, white grain. (Tassilo × Kron) × Heines IV. Heine, Germany.
Minister **O**	A biscuit-making variety; white grain liable to sprout in a wet harvest. Short, stiff straw.	White chaff, white grain. Benoist 40 × Prof. Delos. Gembloux, Belgium.
Hybrid 46 **G**	Suitable for very fertile conditions because of its very short stiff straw and good resistance to yellow rust. Susceptible to loose smut.	White chaff, red grain. Benoist 40 × other hybrids. Marsters, King's Lynn.
Elite Lepeuple **G(N)**	Combines good yield with high milling and good bread-making quality.	White chaff, red grain. Bellevue × Bersee. Lepeuple, France.
Banco **O**	A late maturing Scandinavian type. Fairly long thin-walled straw. Grain of good milling and bread-making quality.	White chaff, red grain. Bankuter 178 crossed with Swedish varieties. Weibull, Sweden.
N.59 **S**	Recommended only for use in the north where it has given good yields. Straw fairly long but stands well. Good milling quality grain.	White chaff, red grain. Single Plant Selection. Milns, Chester.
Dominator **O**	An early variety with high milling and bread-making quality. Short straw.	White chaff, red grain. Jubilegem × Atle. Milns, Chester.
Milfast **O**	High milling and bread-making quality and short stiff straw. Liable to be attacked by yellow rust. Outclassed in yield.	White chaff, red grain. Atle × Holdfast. Milns, Chester.

RECOMMENDED LIST OF SPRING WHEATS 1961

Varieties are in order of expected yields under average conditions.	Jufy I. G(N)	Koga II. G	Phoebus G(N)	Svenno. G	Atson. O	Peko. O	Atle. S
Agricultural Characters:							
Standing power . .	8½	8	7	7½	7	7½	7
Shortness of straw .	6	6	4½	5½	5½	3½	6
Resistance to shedding	5	7	4	6	7	7	7
Resistance to sprouting	7	7	7	5	7	7	8
Resistance to yellow rust	5	8	7	6½	7	9	8
Resistance to loose smut	9	7	9	4	6½	8	7
Resistance to mildew .	6	6	7	7	6	6	7
Earliness of ripening .	6	5½	6	7½	6	5	5½
Quality of Grain:							
Milling quality . .	5	5	2	9	9	3	9
Bread-making quality .	5	7	3	9	8	3	7
Biscuit-making quality	4	2	8	2	2	8	3

Jufy I **G(N)**	Very heavy yielding with short stiff straw. Grain of low quality.	Red chaff, red grain. Jubilegem × Fylgia. Gembloux, Belgium.
Koga II **G**	Very heavy yielding with short stiff straw. Milling quality only moderate, bread-making quality fairly good. Liable to be attacked by black rust, particularly in south-western England. Good tolerance of manganese deficiency.	White chaff, red grain. (Heines Kolben × Garnet) × (Heines Kolben × Raeckes Weisspelziger). Heine, Germany.
Phoebus **G(N)**	Heavy yielding, suitable for biscuit-making. Straw fairly stiff and of medium length. Tends to shed when over-ripe.	Red chaff, red grain. Jubilegem × Fylgia. Dumon, Belgium.
Svenno **G**	Very early maturing. Straw fairly stiff; grain of very high milling and bread-making quality. Somewhat susceptible to sprouting.	White chaff, red grain. (Marquis × Hâtif Inversable) × (Extra Kolben × Swedish land variety). Weibull, Sweden.
Atson **O**	High milling and bread-making quality. Short, fairly stiff straw. Higher yields, and slightly earlier than Atle.	White chaff, red grain 8473 × (Marquis × Hâtif Inversable). Weibull, Sweden.
Peko **O**	A variety with stiff, fairly long straw, with grain suitable for biscuit-making. Liable to be attacked by black rust, particularly in south-western England.	White chaff, red grain. Peragis × Heines Kolben. Heine, Germany.
Atle **S**	Recommended only when good resistance to sprouting is required, with high milling quality. Has given its best yields in the south and west.	White chaff, red grain. Extra Kolben × Saxo. Weibull, Sweden.

BARLEY

RECOMMENDED LIST OF SPRING BARLEYS 1961

Varieties are in order of expected yields under average conditions.	Rika. G	Proctor. G	Union. G(N)	Freja. S	Provost. O	Maythorpe. O	Earl. S
Agricultural Characters:							
Standing power . . .	7½	7	7	5½	7	5	3
Shortness of straw . . .	7½	8	7	8½	6½	8	5
Resistance to loose smut .	3	8	4½	4	8	8	8
Resistance to mildew . .	5	4½	7½	4½	4½	4½	4
Earliness of ripening . .	7½	5½	8	8½	4	8	7½
Malting quality of grain: (Greatly influenced by conditions of growth) . . .	2	‡8	4	4	‡7	‡7	‡7

‡ Approved by the Institute of Brewing as malting barleys.

Rika G	Very heavy yielding and very stiff straw. Recommended as a feeding barley for more fertile soils or when liberally manured. Susceptible to loose smut.	2-row lax ear. Kenia × Isaria. Weibull, Sweden.
Proctor G	Heavy yield, with short stiff straw. Grain small but of high malting quality. Recommended for use in the main malting barley areas and where extreme earliness is not a major consideration.	2-row semi-lax ear. Kenia × Plumage-Archer. Plant Breeding Institute, Cambridge.
Union G(N)	Early maturing barley with stiff straw of medium length and having good resistance to mildew.	2-row lax ear. Weihenstephaner 6831 × Ackermans Donaria × Firlbecks 621. Firlbeck, Germany.
Freja S	Very early maturing, with short, fairly stiff straw. Recommended only as an early maturing feeding barley.	2-row lax ear. Victory × Opal. Svalöf, Sweden.
Provost O	Good malting quality variety, ripening later than Proctor. Grain small.	2-row semi-lax ear. Kenia × Spratt-Archer. Plant Breeding Institute, Cambridge.
Maythorpe O	For use where an early maturing malting quality variety is required. Short straw.	2-row semi-dense ear. Irish Goldthorpe × Maja. Plant Breeding Institute, Cambridge.
Earl S	Good malting quality with early maturity, but rather long weak straw.	2-row lax ear. Selection from Spratt-Archer. Plant Breeding Institute, Cambridge.

RECOMMENDED VARIETY OF WINTER BARLEY

Pioneer **G**	Similar to the spring variety Earl in straw, ear and grain characters, but is winter hardy. Cannot be used as a spring variety. Early maturing; grain of good malting quality. Resistant to loose smut. Appears to be best suited to soils of good or medium fertility.	2-row lax ear. Tschermaks 2-row × Spratt-Archer. Plant Breeding Institute, Cambridge.

OATS

RECOMMENDED LIST OF SPRING OATS 1961

Varieties are in order of expected yields under average conditions.	Condor. G(N)	Blenda. G	Sun II. O	Manod. G(N)	Maldwyn. G	Milford. S
Agricultural Characters:						
Standing power	5	5	5	6	5½	9
Shortness of straw	8	5½	5½	5	6½	9
Yield of straw	6	6	6½	6½	6	5
Resistance to mildew	3	3½	3	8	4½	3
Resistant to stem eelworm				*		*
Earliness of ripening	5½	5½	5	5	5½	4½
Quality of Grain:						
Kernel content	6	7	6½	6½	5½	7½
Size	7½	7	7	6½	3	7

Condor **G(N)**	Very heavy yielding variety with short straw. Grain large.	White grain. Minor × Expres. CIV., Holland.
Blenda **G**	Slightly earlier than Sun II. Reliable and heavy yielding under a wide range of conditions. The grain has a high kernel content.	White grain. Star × Eagle. Svalöf, Sweden.
Sun II **O**	Reliable and heavy yielding under a wide range of conditions, but slightly later maturity and lower kernel content than Blenda.	White grain. Star × Eagle. Svalöf, Sweden.
Manod **G(N)**	The resistance of this variety to mildew, crown rust and oat stem eelworm makes it of special value in the south-west and west. Similar to Sun II in most other respects, but stiffer.	White grain. Tama × 01751/10. Welsh Plant Breeding Station.
Maldwyn **G**	Early maturing. Tillers freely, gives good results at low fertility levels. Grain small.	(Previously S.221) White Grain. Victory × Radnor Sprig. Welsh Plant Breeding Station.

Milford
S

Straw exceptionally short and stiff. Under conditions of medium or low fertility, yields only moderate. High kernel content. Recommended only where lodging can be expected in other varieties, and for soils infested with stem eelworm.

(Previously S.225). White grain.
Victory × S.172.
Welsh Plant Breeding Station.

RECOMMENDED LIST OF WINTER OATS 1961

Varieties are given in order of expected yields under average conditions.	Penrhyn. G(N)	Powys. G	Pennant. G(N)	S.147 O	Barnwell. G(N)	S.172. G
Agricultural Characters:						
Standing power	5	7	6	5	7½	9
Shortness of straw	4	6½	6	3	6	9
Yield of straw	6	5½	5½	6	5½	5
Winter hardiness	6½	7	7	7	7	7½
Resistance to mildew	7	6	5	5½	5½	4
Resistant to stem eelworm			*		*	*
Earliness of ripening	4	7	6½	6	4½	5
Quality of Grain:						
Kernel content	7	7½	7	7½	7½	7
Size	7½	5½	8	8	5½	5

Penrhyn
G(N)

Very heavy yielding. Straw in the S.147 class. Suitable only for soils of moderate fertility. Late maturing.

White grain.
S.147 × (Unique × (Marvellous × Grey Winter)).
Welsh Plant Breeding Station.

Powys
G

Straw shorter and stiffer than S.147; can give slightly higher yields of grain. Suitable for soils of good fertility.

White grain.
S.147 × S.172.
Welsh Plant Breeding Station.

Pennant
G(N)

Resistant to stem eelworm. Yield similar to Powys but straw weaker.

White grain.
S.147 × S.172.
Welsh Plant Breeding Station.

S.147
O

Useful for moderately fertile soils, but liable to lodge under highly fertile conditions.

White grain.
Marvellous × Grey Winter.
Welsh Plant Breeding Station

Barnwell
G(N)

Resistant to stem eelworm. Slightly stiffer than Powys, but yield not quite as high. Rather late maturing.

White grain.
Grey Winter × S.172.
Plant Breeding Institute, Cambridge.

S.172
G

Very short, stiff straw. Resistant to stem eelworm. Where the other recommended winter varieties will stand, they may be expected to give higher yields.

White grain.
(Kyko × Grey Winter) × (Bountiful × Grey Winter).
Welsh Plant Breeding Station.

POTATOES

Varieties Recommended for Lifting as FIRST EARLIES

	Arran Pilot G	Home Guard G	Ulster Premier. G	Ulster Chieftain. S	Ulster Prince. S
Early bulking	5	5	6	6	4
Tubers:					
Size	6	4	5	5	8
Uniformity	5	8	4	8	7
Freedom from defects	5	8	6	4	6
Number per plant	8	9	8	7	4
Field Characters:					
Resistance to dry rot, etc.	3	7	4	5	5
Resistance to drought	7	3	4	5	7
Resistance to blight in foliage	4	5	3	3	4
Resistance to blight in tubers	3	4	3	3	3
Resistance to common scab	8	6	4	–	–
Resistance to leaf roll	5	6	5	4	5
Resistance to severe mosaic	2	3	5	7	5
Tolerance to virus	3	5	6	6	6

Arran Pilot **G**	A general purpose early bulking variety; yield also high at maturity as second early. Earliness varies with type of haulm. Sprouting early and rapid. Susceptible to dry rot; fairly resistant to common scab. Fairly good recovery from frost.	Shape—kidney. Haulm—medium height, spreading. Mackelvie, 1930.
Home Guard **G**	Requires moist conditions. Tubers uniform, small to medium. At maturity suitable for crisping. Sprouting early and rapid. Fairly resistant to dry rot.	Shape—oval. Haulm—medium height, open. Howie, 1943.
Ulster Premier **G**	A very early bulking variety. Tubers, numerous, variable in size, small under dry conditions. Cooking quality very good.	Shape—kidney. Skin—part-coloured pink. Haulm—low to medium spreading. Clarke, 1945.
Ulster Chieftain **S**	A very early bulking variety, maturing early. Tubers very uniform, liable to cracking and hollowness at maturity. Recommended only for early lifting.	Shape—oval. Haulm—low, compact. Clarke, 1938.
Ulster Prince **S**	Tubers marketable early, but few per plant, rapidly becoming large. Skin, tender. Sprouting slow, emergence can be irregular. Recommended only for large uniform tubers at end of first early season.	Shape—kidney Eyes—few Haulm—medium height, compact. Clarke, 1947.

Varieties Recommended for Lifting as

SECOND EARLIES

	Craigs Alliance. G	Craigs Royal. G	Ulster Dale. G
Yield	6	6	7
Tubers			
Size	5	6	8
Uniformity	7	6	7
Freedom from defects	8	6	7
Number per plant	7	8	6
Cooking Quality:			
Freedom from discoloration	7	6	5
Flouriness	5	6	5
Field Characters:			
Resistance to dry rot, etc.	7	5	5
Resistance to drought	4	6	6
Resistance to blight in foliage	4	5	4
Resistance to blight in tubers	5	5	4
Resistance to common scab	6	2	5
Resistance to leaf roll	4	5	5
Resistance to severe mosaic	4	4	3
Tolerance to virus	4	4	6

Craigs Alliance G	Recommended for use as a second early although of first early maturity. Yield very good at maturity, except under dry conditions. Tubers uniform, medium size. Fairly resistant to dry rot.	Shape—oval. Haulm—medium height, open. Scottish Society for Research in Plant Breeding, 1948.
Craigs Royal G	Good yield and quality. Skin colour variable. Rather susceptible to common scab and severe mosaic. The use of certified seed is especially important as tobacco veinal necrosis has occurred in some seed stocks.	Shape—oval. Skin—part-coloured pink. Haulm—medium height. Scottish Society for Research in Plant Breeding, 1948.
Ulster Dale G	A high yielding variety. Tubers uniform, attractive. Cooking quality variable. Growth rapid, uniform.	Shape—kidney, slightly flat. Haulm—medium height, very compact. Clarke, 1950.

Varieties Recommended for Lifting as
MAINCROPS

	Arran Viking G	King Edward. G	Majestic. G	Ulster Beacon. G	Ulster Supreme. G	Ulster Tarn. G	Orion. S
Yield:	7	5	6	6	8	5	6
Tubers:							
Size	9	6	8	9	9	7	8
Uniformity	6	6	6	9	7	8	6
Freedom from defects	6	7	4	5	7	6	6
Number per plant	7	9	9	5	6	7	9
Cooking Quality:							
Freedom from discoloration	6	8	5	9	9	5	5
Flouriness	4	6	8	5	8	7	6
Field Characters							
Resistance to dry rot, etc.	6	7	6	6	5	5	5
Resistance to blight in foliage	8	3	4	3	6	4	8
Resistance to blight in tubers	5	3	7	7	2	6	7
Resistance to common scab	8	8	4	6	3	4	4
Resistance to leaf roll	4	6	5	5	6	8	5
Resistance to severe mosaic	4	4	6	5	9	8	6
Tolerance to virus	4	4	5	4	6	4	6

Arran Viking G	High yielding early maincrop. Keeping quality good. Blight resistance fair. Resistant to common scab. Stems thick; stolons long, but tubers do not surface.	Shape—oval. Haulm—tall, upright. Mackelvie, 1945.
King Edward G	Requires very good conditions. Highest quality for the English market. Very susceptible to blight; rather resistant to common scab. Red King Edward has skin wholly pink. Susceptible to wart disease, so must not be planted in wart infested areas.	Shape—oval. Skin—part-coloured pink Haulm—tall, upright. Butler, 1902.
Majestic G	A most useful general purpose variety; yield good in most districts. Tubers fairly uniform, severe cracking sometimes occurs. Keeping quality, satisfactory.	Shape—kidney. Haulm—medium height, spreading Findlay, 1911.
Ulster Beacon G	Early maincrop giving high yields of ware when seed is well sprouted. Requires rain early in season. Foliage susceptible to blight. Tubers well clustered, shallow in ground, sample very uniform, rarely discolour after cooking.	Shape—oval. Haulm—medium to low, compact. Clarke, 1934

Ulster Supreme **G**	Very high yielding, of late maturity. Resistant to severe mosaic. Should be planted early and allowed to mature, otherwise tubers are liable to damage.	Shape—oval. Haulm—tall, erect. Clarke, 1946.
Ulster Tarn **G**	Early maincrop giving very uniform medium-sized ware. Resistant to leaf roll and severe mosaic. Sometimes highly flavoured.	Shape—oval. Haulm—medium height, upright, open Clarke, 1955.
Orion **S**	Early maincrop, with some blight resistance. Rather susceptible to dry rot. Dry matter content high. Recommended only for chipping or processing.	Shape—short, oval. Flesh—yellow. Eyes—medium. Haulm—medium, upright. Smith, 1947.

SUGAR BEET

RECOMMENDED LIST OF SUGAR BEET 1961

Varieties printed in alphabetical order—figures based on results for the years 1958-60

Varieties.	Yield of sugar.		Yield of roots.		Sugar content %	Yield of tops.		Bolters. %	
	%	Cwts. per acre.	%	Tons per acre.		%	Tons per acre.	Normal.	Early sowing.
Grown in Trials for a Long Period:									
Battle's E . .	100	55·7	103	18·2	15·7	101	13·9	0·5	2·0
Battle's N . .	98	54·6	99	17·5	16·0	100	13·8	1·4	5·3
Bush E . . .	100	55·7	100	17·7	16·2	107	14·8	0·8	3·0
Bush N . . .	99	55·1	98	17·3	16·4	101	13·9	1·0	3·4
Cambro* . .	95	52·9	94	16·6	16·4	96	13·2	0·3	0·7
Hilleshog E .	101	56·3	103	18·2	15·9	99	13·7	1·9	6·5
Hilleshog N .	102	56·8	101	17·9	16·3	100	13·8	1·8	5·8
Hilleshog Polyploid	101	56·3	99	17·5	16·5	97	13·4	1·5	4·7
Johnson's E .	100	55·7	100	17·7	16·2	106	14·6	1·0	3·4
Johnson's N .	98	54·6	97	17·2	16·4	102	14·1	1·2	4·1
Sharpe's Klein E .	103	57·4	105	18·6	15·9	101	13·9	0·9	3·1
Sharpe's Klein Polybeet . .	103	57·4	100	17·7	16·7	96	13·2	1·1	4·2
Grown in Trials for a Shorter Period:									
Gartons 632 .	(100–102)	—	(99–101)	—	(16·2–16·4)	(106–107)	—	(1·8–2·2)	—
Zwaanesse III .	(101–103)	—	(100–102)	—	(16·0–16·2)	(97–99)	—	(0·4–0·6)	(1·5–2·0)

* For particular use only.

Battle's E	Average yield of sugar from roots of relatively low sugar content. Medium sized tops. Bolting low.	Battle & Webb, Ltd., Potterhanworth, Lincs.
Battle's N	Rather below average yield of sugar from roots of average sugar content. Medium sized tops. Rather above average bolting.	Battle & Webb, Ltd., Potterhanworth, Lincs.
Bush E	Average yield of sugar and roots. Large tops. Bolting below average.	Bush-Johnson's Ltd., Maldon, Essex.
Bush N	Average yield of sugar from roots of fairly high sugar content. Medium sized tops. Bolting average.	Bush-Johnsons Ltd., Maldon, Essex.
Cambro	*Recommended only for very early sowings, especially in northern areas, on account of its extremely low bolting.* Low yield of sugar from roots of fairly high sugar content. Small tops.	Cambridge Plant Breeding Institute.
Gartons 632	Above average yield of sugar. Large tops. Bolting average.	Gartons Ltd., Warrington, Lancs.
Hilleshog E	Average yield of sugar from roots of rather low sugar content. Medium tops. Bolting fairly high.	C. W. Marsters Ltd., King's Lynn, and Cannell & Sons Ltd., Loddon, Norfolk.
Hilleshog N	Fairly high yield of sugar from roots of average sugar content. Medium sized tops. Bolting fairly high.	C. W. Marsters Ltd., King's Lynn, and Cannell & Sons Ltd., Loddon, Norfolk.
Hilleshog Polyploid	Average yield of sugar from roots of fairly high sugar content. Rather small tops. Bolting moderate.	C. W. Marsters Ltd., King's Lynn, and Cannell & Sons Ltd., Loddon, Norfolk.
Johnson's E	Average yield of sugar and roots. Large tops. Bolting moderate.	Bush-Johnson's Ltd., Boston.
Johnson's N	Rather below average yield of sugar from roots of fairly high sugar content. Medium sized tops. Bolting moderate.	Bush-Johnson's Ltd., Boston.
Sharpe's Klein E	High yield of sugar from roots of rather below average sugar content. Medium sized tops. Bolting moderate.	Charles Sharpe & Co. Ltd., Sleaford.
Sharpe's Klein Polybeet	High yield of sugar from roots of high sugar content. Small tops. Bolting moderate.	Charles Sharpe & Co. Ltd., Sleaford.
Zwaanesse III	Above average yield of sugar. Medium sized tops. Bolting low.	Zwaanesse Inc., The Hague Netherlands

VARIETIES OF MANGEL AND FODDER BEET

I. Mangels—Low Dry-matter

Globe Shape

Corners Short Top (Y)
Giant Orange Globe (O)
Large Orange Globe (O)
Lord Warden (O)
Monarch (Y)
New Century (O)
New Selection (O)
Orange Globe (O)
Prizewinner (Y)
Q.Q. (Y)
Smithfield (Y)
Somerset Golden Globe (O)
Yellow Globe (Y)
Windsor (Y)

Intermediate Shape

Brocks Red (R)
Brocks Yellow (Y)
Giant Orange Intermediate (O)
Golden Tankard (O)
Leader (O)
New Cross (O)
New Intermediate (O)
Orange Intermediate (O)
Red Chief (R)
Red Gatepost (R)
Red Intermediate (R)
Sungold (O)
Unique (R)
White Knight (W)
Wintergold (O)

II. Mangels—Medium Dry-matter

Hunsballe Runkelroe XI (O)
Ideal (Y)
Øtofte Nova XI (O)
White Chief (W)

III. Fodder Beet—Medium Dry-matter

Pajbjerg Korsroe XI (Y)
Pajbjerg Rex XI (W)
Red Øtofte XI (R)
Yellow Daeno XI (O)
White Øtofte XI (W)

IV. Fodder Beet—High Dry-matter

Hinderupgaard XI (W)
Hunsballe Sukkerroe XI (W)

Skin colour: O = Orange R = Red Y = Yellow W = White

TYPES OF KALE

The table below, based on trials grown during 1954–59, gives a general comparison of the behaviour of *the different types* over the whole season. The figures for both Marrow Stem and Thousand Head kale represent the mean for a number of varieties ; the figures for the other types are based on results for material from a single reliable source.

Types of Kale	* Yield of dry-matter (over whole season).			Hardiness 9=v hardy 0=non-hardy.	Flowering 9=v late 0=early.	Notes
	Total	Leaf	Stem			
Marrow Stem:						
Green . . .	120	47	73	2	3	Stem palatable.
Purple . . .	110	50	60	3	2	Stem moderately palatable.
Thousand Head:						
Normal . . .	125	62	63	7	5	,,
Dwarf . . .	110	65	45	8	6	Stem not palatable.
Hungry Gap:	80	42	38	5	9	Susceptible to mildew and aphid attack.
Rape Kale:	80	42	38	5	8	,,
Horticultural:						
Asparagus . .	75	42	33	6	7	,,
Green Curled Scotch	105	53	52	7	6	Stem not palatable.

* As a percentage of the mean total yield for all types.

VARIETIES OF BEANS

WINTER BEANS

Throws M.S. (Haslers) has consistently given above average yields. This is a " synthetic " variety composed of four or more lines, separately raised but combined before marketing, with a view to exploiting hybrid vigour (a technique being pursued by other breeders).

S.Q. (Gartons) has given average yields.

SPRING BEANS

Tick Beans are particularly suitable as a cash crop for the pigeon trade. Seeds round or flat oval; small with a 1,000 corn weight between 10 and 20 oz.

Albyn Tick (S.S.R.P.B.) Uniform and early, but outyielded by some newer varieties; seed rather large.

Blue Rock (Miln's) Medium late; consistently above average yield. Small round seed.

Garton's Tick No. 6 (Gartons) Medium late; with rather above average yields. Small round seed.

Hedingham (Pertwees)	Medium late; with above average yields. Seed medium small.
Herz Freya (Herz, Germany)	Early; with medium short straw. Seed small oval. Yield trials inconclusive.
Minor (Gembloux, Belgium)	Medium late; above average yield. Seed small.

HORSE BEANS. Seeds usually flat oval; larger than tick beans with a 1,000 corn weight between 20 and 30 oz. The type is usually earlier and shorter strawed than the tick bean type but exceptions occur.

Granton (Scottish)	Early, fairly short-strawed and average yield.
Suffolk Red (Farmer's stock)	Seeds red and white mixed ; late. Capable of high yield but rather inconsistent.

LARGER SEEDED BEANS : 1,000 corn weight over 30 oz. Difficulties of mechanised drilling of the large seed have limited the agricultural use. Characteristically even earlier and shorter strawed than horse beans. Some of the stocks are related to the horticultural broad beans. Mazagan (English) and Wier (Dutch) are examples.

TYPES OF SWEDE

The National Institute of Agricultural Botany has been testing since 1953 more than 130 British swedes, grouped into five major types :

Light Purple Skin Group	Generally the earliest maturing, they give good root yields, with rather low dry-matter content and they are not especially winter hardy.
Dark Purple Skin Group	Rather later maturing and more hardy. The higher dry-matter compensates for the rather lower root yield.
Green Skin Group	Includes the hardiest and latest maturing of the swedes grown in England, the relatively high dry-matter content results in good yields of dry-matter despite the rather low root yield.
Bronze Skin Group	Mixed in character, with a wide range of maturity and hardiness, as well as of dry-matter content.
Hardy Dark Purple Skin Group	Practically confined to Scotland, and does not appear suited to English conditions.

There is no clear demarcation between the Light Purple and the Dark Purple groups. The skin colour is affected by sunlight, and tends to be deeper in those with small tops, and to depend on growing conditions.

Selection undertaken during seed multiplication can substantially alter the detailed characters of a stock within a few generations. As a result stocks which bear the same variety name but which have been maintained by different seed houses frequently show important differences.

VARIETIES OF MAIZE

Variety.	Country of origin.	Maturity class 9 = early 0 = v. late.	Relative yield of dry-matter for silage.	Notes.
C.I.V.4	Netherlands	9	95	Early group. Suitable for grain production in southern England.
Inra 200	France	9	95	
Prior	Netherlands	9	85	
Caldera 331	Netherlands	8	90	Medium/early silage group.
Foliant	Netherlands	8	100	
Inra 244	France	8	90	
Caldera 401	Netherlands	7	90	
Caldera 402	Netherlands	7	105	
Caldera 501	Netherlands	7	95	
C.I.V.7	Netherlands	7	105	
Inra 258	France	7	105	
Wisconsin 270	U.S.A.	7	90	
Inra 353	France	6	100	Medium silage group.
Kingscrost KC3	U.S.A.	6	105	
Orla 266	Switzerland	6	105	
Warwick 277	Canada	6	95	
Wisconsin 273	U.S.A.	6	95	
Pioneer 395	U.S.A.	5	105	
Wisconsin 335A	U.S.A.	5	100	
Wisconsin 355A	U.S.A.	5	105	
Maisking V	U.S.A.	4	105	Medium/late silage group.
Pioneer 383	U.S.A.	4	105	
Kingscrost KS2	U.S.A.	2	110	Green feeding group: too late for satisfactory silage.
White Horse Tooth	Various	0	110	

VARIETIES OF LUCERNE

EARLY TYPE

French:

Chartrainvilliers
Cardinal
Du Puits
Émeraude
Étoile du Nord
Flandria
Florimond-Desprez 100
Gamma
Omega
Orchésienne
Ormelong
Socheville
W.268

English:

Eynsford

Swedish:

Alfa

MID-SEASON TYPE

Southern France:

Provence

Western France:

Maraîs
Poitou

New Zealand:

Marlborough
Strain B

Hungarian

LATE TYPE AND EXTRA LATE TYPE

Rhizoma
Ladak
Nomad

Appendix VI

WEED CONTROL BY SELECTIVE HERBICIDES*

Choice of Herbicide

As the range of chemicals available to the farmer is extended, the problem as to the choice of the appropriate herbicide becomes increasingly complex. A number of factors must now be considered in deciding the most efficient and economical treatment to use under any particular set of circumstances. The crop concerned and the weeds present are of primary importance ; but consideration must also be given to the tolerance of the variety to the herbicides available, the stage of growth of the crop and weeds, the time of spraying, the ease of application and efficiency of weed control and, of course, cost. Where the action of the herbicide is mainly through the roots, soil type and soil conditions at spraying must also be taken into account.

RECOMMENDED HERBICIDES FOR CROPS

Cereals

The maximum amounts of herbicide than can be safely applied as liquid sprays when cereals are at their most resistant stage are shown in Table I. Winter cereals are most resistant when fully tillered in the spring but before shooting, spring cereals from the five-leaf stage until shooting. In general winter-sown cereals are more resistant to herbicides than spring-sown cereals.

A dosage rate lower than the maximum safe dose may be sufficient to give adequate control and in deciding the dosage rate reference should also be made to Table II.

Amounts of synthetic plant growth regulator herbicides are given as oz. per acre of acid equivalent of active isomer, except mecoprop where doses are given as total of dextro- and laevo-rotary isomers. The amounts refer to products not containing an added surface-active agent, except 2,4-D ester in which such an agent has to be included in the formulation of the normal type of emulsifiable concentrate. The suffix " salt " indicates sodium, potassium, ammonium and amine formulations.

Amounts of DNOC and dinoseb are given as lb. per acre of parent nitrated phenol.

Volume Rates

Normally, growth regulator herbicides (MCPA, 2,4-D, MCPB, 2,4-DB, mecoprop and MCPA/2,3,6-TBA mixtures) should not be sprayed at rates of less than 10 gal. per acre. For mecoprop, the minimum volume should be 20 gal. per acre ; whilst the maximum volume for MCPA/2,3,6-TBA should be 30 gal. per acre. DNOC and dinoseb-ammonium should normally be applied at rates of 60–100 gal. per acre ; dinoseb-amine will give satisfactory results in volume rates down to 40 gal. per acre. Sulphuric acid is normally diluted and applied at 100 gal. per acre.

Cereals Undersown with Grass and Clover or Lucerne

Sulphuric acid can be used safely, as for cereals, either before the seeds are drilled or after drilling and before germination. DNOC and dinoseb are safe, as used for cereals, if the undersown seeds are drilled (not broadcast), and spraying takes place at least seven days before the grass and clover seeds are drilled, or during the three days following drilling. Alternatively, dinoseb

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* Recommendations based on the Weed Control Handbook 1960, by permission of Blackwell Scientific Publications, Ltd, Oxford.

TABLE I

MAXIMUM SAFE AMOUNTS OF HERBICIDES FOR CEREALS

Chemical.	Unit of Dose.	Wheat.		Oats.		Barley.		Rye.
		Winter.	Spring.	Winter.	Spring.	Winter.	Spring.	Winter.
MCPA-salt	oz./ac.	32	32	32	32	32	32	32
2,4-D-amine	oz./ac.	24	16	16	NR	16	16	24
2,4-D-ester	oz./ac.	16	8	4	NR	8	8	16
MCPB-salt	oz./ac.	48	48	48	48	48	48	No Evidence
2,4-DB-salt	oz./ac.	48	48	32	24	48	48	No Evidence
Mecoprop salt	oz./ac.	56	56	56	56	56	56	NR
MCPA/2,3,6-TBA mixture	oz./ac.	12 + 4	12 + 4	12 + 4	12 + 4	12 + 4	12 + 4	12 + 4
DNOC	lb./ac.	8	8	8	8	8	8	8
Dinoseb-ammonium	lb./ac.	1·5	1·5	1	1	1·5	1·5	1·5
Dinoseb-amine	lb./ac.	2	2	1·5	1·5	2	2	2
Sulphuric acid	gal./ac.	11·5	10	10	8	10	10	10

NR—not recommended for use.

Special Notes

1. MCPA or 2,4-D applied in a dust carrier: twice the quantities given above can be used.

2. DNOC dosage rates are for the unactivated form. Where an activated product is used the maximum safe amount must be reduced by 25 per cent. During cold weather, or to control weeds in an advanced stage of growth, dosage rates may be increased by 25 per cent for wheat and barley, but increased scorch of the cereal may occur. DNOC can be sprayed on spring cereals from the 3-leaf stage up to shooting.

3. Dinoseb: maximum dosage rates should be decreased by 20 per cent in warm, moist weather and may be increased by a similar amount during cold, dry weather. Dinoseb can be sprayed on spring cereals from the 3-leaf stage up to "shooting".

4. Sulphuric acid: dosage rates are expressed as pure acid.

5. MCPB can be used on spring cereals from the 1-leaf stage up to "shooting".

6. 2,4-DB can be used on spring barley and spring oats from the 1-leaf stage up to "shooting".

7. Mecoprop can be sprayed on spring barley and spring oats from the 1-leaf stage up to "shooting", also on Koga II spring wheat.

8. Spring Oats: between the 1-leaf and 5-leaf stages use MCPA at rates up to 24 oz. per acre; MCPB at rates up to 48 oz. per acre; 2,4-DB at rates up to 24 oz. per acre; mecoprop at rates up to 56 oz. per acre.

may be applied after the clovers have developed two trifoliate leaves. Cereals undersown with lucerne may be treated in a similar manner. MCPB-salt at rates up to 32 oz. per acre may be used on undersown cereals provided most of the clovers have developed the first trifoliate leaf and cereal is at a suitable growth stage (Table I). 2,4-DB-salt may also be used at rates up to 32 oz. per acre, again provided the clovers have reached the first trifoliate leaf stage. 2,4-DB is slightly more toxic to red clover than MCPB, but the leaf deformities produced do not persist more than six to eight weeks. The cereal must also be at a suitable growth stage (Table I).

MCPA and 2,4-D are not normally recommended as seedling clovers are very susceptible to these herbicides. In an emergency, application of low doses of liquid or dust preparations may be made to control susceptible weeds. The clovers should have reached the two trifoliate leaf stage and the weeds grown sufficiently to shield the seedlings. MCPA is safer than 2,4-D for use on red clover but not on white clover. Crops undersown with lucerne should not be sprayed with either MCPA or 2,4-D.

Dredge Corn

Dredge corn containing cereals only may be treated in the same way as straight cereal crops, provided the maximum safe dose for the most susceptible cereal in the mixture is not exceeded.

Mixtures containing peas and cereals only may be sprayed with MCPB-salt at rates up to 32 oz. per acre when the peas have developed between three and six leaves. Dinoseb can also be used on mixtures of peas and cereals only, providing the specified conditions for use of dinoseb on these crops are followed.

Peas (Field, Drying and Vining)

Dinoseb as the ammonium salt may be used on peas for drying at dosages of up to 2 lb. per acre applied at high volume. Spraying should only be carried out when the temperature of the day is above 55° F. and will not rise above 80° F. Above and below these temperature limits spraying should not be carried out. Where good growing conditions have prevailed during the days preceding spraying, and the temperature is high on the day of spraying, it may be becessary to reduce the dosage maximum ; at over 70° F. and where pea growth is " soft ", 1 lb. per acre should be regarded as maximal.

Peas should be sprayed after three leaves have expanded, usually about 3 in. high but before reaching a height of 10 in. The crop should not be sprayed when wet, nor until a week has elapsed following damage by high winds or blowing soils.

Where the field has received a presowing application of TCA not more than half the normal dose of dinoseb-ammonium should be applied.

Dinoseb-amine may be used on drying peas and certain varieties of picking and vining pea. It is preferable to dinoseb-ammonium for picking and vining peas as it causes less scorch. The maximum safe dosage rate is 3 lb. per acre at 40 gal. per acre and above, provided the temperature is between 45° F. and 85° F. Crops which have been damaged by wind or previously treated with TCA—the precautions given above must be followed (see dinoseb ammonium).

MCPB at rates of up to 32 oz. per acre may be applied to certain varieties when the peas have from 3 to 6 expanded leaves. Fat hen (Chenopodium album) and creeping thistle (Cirsium arvense) are particularly susceptible to MCPB.

As certain varieties of peas, especially peas for vining, are less tolerant to sprays than others, it is important to ascertain before spraying that the variety is tolerant to the spray used.

Field Beans

Winter-sown crops can be sprayed with dinoseb-amine at rates up to 1½ lb. per acre at high volume. The beans should only be sprayed when they are about 3 in. high, while growth is still " hard ", i.e. before rapid growth starts.

Sugar Beet and Fodder Beet

Pentachlorophenol in a non-persistent, emulsifiable oil formulation can be applied as a pre-emergence treatment at rates up to 3 lb. per acre in medium or high volume. This herbicide acts mainly as a contact weed killer and will only be of use where the weeds have emerged. Spraying should not take place later than 3 days before the crop is expected to emerge.

As an emergency measure, nitrate of soda at the rate of 2½ cwt. per acre in 100 gallons of water may be applied once the beet has two true leaves expanded. To be effective a wetting agent must be applied. Not all the proprietary wetting agents are suitable and advice should be sought as to suitable wetting agents and amounts required. The best results are obtained under warm humid conditions with a spell of fine weather following the spraying.

Carrots

Certain mineral oils may be sprayed on to carrots once the cotyledons are fully developed and before the carrots reach " pencil thickness ", at the rate of 80 gal. per acre. Half this rate can be used if the spray is directed on to the rows only. Most tractor vapourising oils can be used in a similar manner, but application should not be made until the carrots have reached the two-leaf stage.

Clovers (Direct Sown)

MCPB-salt may be applied to direct-sown red or white clover during the early stages of establishment at doses up to 32 oz. per acre, provided the clovers have developed their first trifoliate leaf. 2,4-DB-salt may also be applied at rates up to 32 oz. per acre to red clover, and up to 48 oz. per acre to white clover after the first trifoliate leaf has developed. MCPB is to be preferred for weed control in red clover unless *Polygonum* species are predominant.

Dinoseb-ammonium or -amine spray may be applied to both red and white clover, provided the plants have developed two trifoliate leaves. Maximum dosage rates are 1½ lb. per acre for the ammonium salt, and 2 lb. per acre for the amine salt in high volume, the dosage rates being reduced by up to 30 per cent if temperatures are high during spraying.

Lucerne

Dinoseb-ammonium at rates up to 1½ lb. per acre or dinoseb-amine at rates up to 2 lb. per acre in high volume may be applied to seedling lucerne. These rates may have to be reduced by up to 30 per cent if the temperature is high on the day of spraying. The lucerne should have developed two trifoliate leaves before spraying is carried out.

2,4-DB-salt at doses up to 48 oz. per acre may be applied, provided the lucerne seedlings have reached the first trifoliate leaf stage. The optimum time for treatment is between the first and fourth trifoliate leaf stages. 2,4-DB should not be applied to lucerne sown direct in the late summer where *Stellaria media* (chickweed) is abundant.

Maize (Fodder and Grain)

Simazine applied as a pre-emergence spray will give a useful control of annual weeds, weed control being less satisfactory under dry conditions. The rate of application should be 1 lb. per acre on light soils, 1½ to 2 lb. per acre on heavy soils or soils rich in organic matter.

2,4-D-amine as a post-emergence spray when the crop is from 3 to 6 in. high, can be used at rates up to 16 oz. per acre.

Kale

Sulphuric acid may be applied to kale when it is between the two- and six-leaf stage and growing vigorously. An 8 per cent v/v solution at 100 gal. per acre may be used at the two- to four-leaf stage, the dosage being increased to a 10 per cent v/v solution at the four- to six-leaf stage. Scorching of the crop occurs, but recovery is rapid under good growing conditions and may be aided by a nitrogen top-dressing. Spraying at the late stage reduces crop scorch and damage, but the control of the weeds may be reduced.

Sodium monochloroacetate at 20 lb. in not less than 20 gal. per acre may be applied to marrow-stem kale between the one- and six-leaf stages. Thousand-head kale should not be sprayed until the two-leaf stage has been reached. Charlock, wild radish, redshank, spurrey and groundsel are susceptible to this spray; fat hen is not controlled.

Leys in Their First Year

The spraying of young leys is advisable when the weeds present are difficult to control by either cutting or grazing, or when a large number of seedling perennial weeds are present. Perennial weeds are increasingly difficult to control by any means after the seedling stage.

MCPA-salt at rates up to 16 oz. per acre can be safely applied to swards containing red clover only, provided the clover is reasonably well established and protected to some extent by a canopy of weeds. This treatment cannot be generally recommended for swards containing white clover ; but as an emergency measure up to 12 oz. of MCPA-salt or 2,4-D-amine per acre can be applied to young leys containing white clover, provided the weed canopy is fairly dense. Even under these conditions some suppression of the clover will occur.

MCPB-salt and 2,4-DB-salt are, however, much less toxic to clovers and are to be preferred for use on young leys. These may be used at rates up to 32 oz. per acre of MCPB-salt and 2,4-DB-salt on swards containing red clover, and 32 oz. per acre of MCPB-salt or 48 oz. per acre of 2,4-DB-salt on swards containing white clover, once the clovers have developed the first trifoliate leaf.

The more expensive dinoseb-ammonium or -amine spray can also be safely applied to leys in their first year, once the clovers have developed two trifoliate leaves : but should only be used when the weeds present cannot be adequately controlled by other means. Dosage rates of up to 1½ lb. per acre of the ammonium salt or 2 lb. per acre of the amine salt in high volume can be used, though some leaf scorch will occur both on the grasses and clovers. These recommended maximum dosage rates must be reduced by up to 30 per cent when the temperature is high during spraying.

Permanent Grass and Long-Term Leys

Spraying can be used to control broad-leaved weeds in established grassland, but should normally be carried out only as part of an overall plan of grassland improvement. The removal of the weeds in itself will not necessarily give an improvement in the sward, unless the ground previously occupied by the weeds is filled up by the desired species of grasses and clovers. This will usually occur only under a system of improved management. Spraying may also be used to control the growth of poisonous or deleterious plants in grassland, whose presence make utilisation risky if not impossible.

MCPA-salt, 2,4-D-amine or -ester must normally be applied at dosage rates high enough to reduce the amounts of clover present in order to give adequate control of the broad-leaved perennial weeds. On grassland containing mainly red clover, MCPA is to be preferred to 2,4-D. Where damage to clovers is to be avoided MCPB-salt and 2,4-DB-salt can be safely used at rates up to 48 oz. per acre.

Spraying treatments can be applied at any convenient time during the spring and summer, provided the weeds are actively growing. Where a hay cut is to be taken, spraying should either take place in the early spring (for buttercups, etc.) or be delayed until regrowth of weeds has occurred after mowing (for thistles, etc.). Under grazing conditions, the sward should be treated at the optimum stage of growth for the control of the major weed, but where damage to the clovers is likely to occur the spraying should be carried out as early in the spring as practicable.

Grasses for Seed Production

Not more than 24 oz. MCPA-salt, 16 oz. 2,4-D-amine, 8 oz. 2,4-D-ester, 40 oz. of mecoprop or 12 oz. MCPA plus 4 oz. 2,3,6-TBA per acre may be applied to established grasses in the season of seed production. Spraying must take place not earlier than 4 to 5 weeks before ear emergence is expected, and not later than ear emergence itself.

WEED SUSCEPTIBILITY

The general response of weeds to some herbicides is given in Table II. Abbreviations used are thus :

S—susceptible—complete or near complete kill.
MS—moderately susceptible—effective suppression of annuals with or without partial mortality. Good control of perennials provided attention is given to the correct timing of the treatment and, if necessary, to management.
MR—moderately resistant—temporary suppression of annuals, the duration depending on the vigour of the crop. Variable effect on perennials and useful control cannot be relied on.
R—resistant—no useful effect.
Sd—seedling stage, i.e. cotyledons to 2–3 leaves.
Yp—young plant stage, i.e. 3–4 leaves to early flower-bud stage.
A, B, P—annual, biennial, perennial, respectively.
SK—shoot kill of perennials.
LTC—long-term control of perennials.
LTCA—long-term control in arable land.
LTCG—long-term control in grassland.
†—total mecoprop (CMPP) in terms of active and inactive isomers in ratio 50/50.
(i)—DNOC activated 4–6 lb. per acre ; inactivated 6–8 lb. per acre.
(ii)—Dinoseb-ammonium 1·5 lb. per acre ; -amine 2 lb. per acre.
*—category related to 20 oz. 2,4-D-ester a.e. per acre.
**—susceptible to 24 oz. 2,4-D-ester a.e. per acre.
(w)—wetting agent should be used.

TABLE II

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Chemical and dose ; oz. acid equivalent per acre.		MCPA-salt		2,4-D-				MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/2,3,6-TBA	DNOC	Dinoseb
				-amine		-ester										
Weed		12	24	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
1. *Achillea millefolium* (P) (Yarrow)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
2. *Aegopodium podagraria* (P) (Ground elder)		R		R		R*		R		R		—		—	—	—
3. *Aethusa cynapium* (A) (Fool's parsley)		—		—		—		—		—		—		—	—	—
4. *Agrimonia eupatoria* (P) (Common agrimony)		R		R		R*		R		R		—		—	—	—
5. *Agropyron repens* (P) (Couch grass)		R		R		R*		R		R		R		R	—	—
6. *Agrostemma githago* (A) (Corncockle)		R		R		R		R		—		—		MR	—	—
7. *Agrostis gigantea* (P) (Common bent-grass)		R		R		R*		R		R		R		R	—	—
8. *Agrostis stolonifera* (P) (Creeping bent-grass)		R		R		R*		R		R		R		R	—	—
9. *Ajuga reptans* (P) (Bugle)		R		R		R*		R		R		R		R	—	—
10. *Allium ursinum* (P) (Ramsons)		R		R		R		—		—		—		—	—	—
11. *Allium vineale* (P) (Wild onion)		—	MR	—	MR	—	MS	—		—		—		—	—	—
12. *Alopecurus myosuroides* (A) (Blackgrass, Slender foxtail)		R		R		R		R		R		R		R	R	R
13. *Amsinckia intermedia* (A)		R		MR		MS		—		—		MR		R	—	MS
14. *Anagallis arvensis* (A)	Sd	MR	MS	MR	MS	MR	MS	MR	MS	MR	MS	MR		MS	S	S
(Scarlet pimpernel)	Yp	R	MR	R	MR	R	MR	R	R	R	R			MR	S	S

15. *Anthemis arvensis* (A)	Sd	R	MR	R	MR	R	MR	R		R		MR	MR	MS	S	S
(Corn chamomile)	Yp	R	R	R	R	R	R					R	MR	MR	MR	MR
16. *Anthemis cotula* (A)	Sd	R	MR	R	MR	R	MR	R		R		MR	MR	MS	S	S
(Stinking mayweed)	Yp	R	R	R	R	R	R					R	MR	MR	R	MR
17. *Anthriscus sylvestris* (P)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
(Cow parsley)																
18. *Aphanes arvensis* (A)	Sd	R		R		R		R		R		—		R	S	—
(Parsley piert)	Yp														S	
19. *Arctium lappa* (B)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
(Greater burdock)																
20. *Arctium minus* (B)		—	MS	—	MS	—	MS*	—		—		—		—	—	—
(Lesser burdock)																
21. *Arenaria serpyllifolia* (A or B)		S		S		S		—		—		—		—	—	—
(Thyme-leaved sandwort)																
22. *Armoracia rusticana* (P)		—	MS	—	MS	—	MS*	—		—		—	MS	—	—	—
(Horse-radish)																
23. *Arrhenatherum elatius* (P)		R		R		R		R		R		R		R	—	—
(Onion couch)																
24. *Artemisia vulgaris* (P)		—	MS	—	MS	—	MS*	—		—		—		—	—	—
(Mugwort)																
25. *Atriplex patula* (A)	Sd	MS	MS	MS	S	MS	S	MR	MS	MS	MS	MS	S	S	S	S
(Common orache)	Yp	MR	MS	MR	MS	MR	MS	R	MR	R	MR	MR	MS	MS	MR	MR
26. *Avena fatua* (A)		R		R		R		R		R		R		R	R	R
(Wild oat)																
27. *Avena ludoviciana* (A)		R		R		R		R		R		R		R	R	R
(Wild oat)																
28. *Bellis perennis* (P)		—	MS	—	MS	—	S	—	MR	—	MR	MS		MS	—	—
(Daisy)																
29. *Brassica juncea* (A)		S		S		—		—		—		—		—	—	—
(Indian mustard)																
30. *Brassica napus* var. *arvensis* (A)		S		S		S		—		—		—		S	—	—
(Rape)																
31. *Brassica nigra* (A)	Sd	S	S	S	S	S	S	S	S	MS	S	S	S	S	S	S
(Black mustard)	Yp	S	S	S	S	S	S	MS	S	MR	MS	S	S	S	S	S
32. *Brassica rapa spp.* (A)	Sd	MS	S	MS	S	MS	S	MS	S	—		MS	S	S	—	—
campestris	Yp	MR	MS	MR	MS	MR	MS	MR	MS			MR	MS			
(Wild turnip)																

TABLE II (*continued*)

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Chemical and dose ; oz. acid equivalent per acre. / Weed		MCPA-salt		2,4-D- -amine		2,4-D- -ester		MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/2,3,6-TBA	DNOC	Dinoseb
		12	24	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
33. *Calystegia sepium* (P)	SK	—	S	—	S	—	S*	—	S	—	—	—		—	—	—
(Bellbine)	LTC	—	MR	—	MR	—	MR*	—	MR	—	MR	—		—	—	—
34. *Calystegia sylvestris* (P)		—		—		—		—		—		—		—	—	—
(Large bellbine)																
35. *Capsella bursa-pastoris* (A)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
(Shepherd's purse)	Yp	MS	S	MS	S	MS	S	MR	MS	MR	MS	MS	S	S	S	S
36. *Cardamine hirsuta* (A)		—		—		—		—		—		—		—	—	—
(Hairy bittercress)																
37. *Cardaria draba* (P)	SK	MS	S	MS	S	MS	S	—		—		—		—	—	—
(Hoary pepperwort)	LTC	MR	MS	MR	MS	MR	MS									
38. *Carduus nutans* (P)		—	MS	—	MS	—	MS*	—	MS	—		—		—	—	—
(Musk thistle)																
39. *Carex spp.* (P)		—	R	R		R*		R		—		—		—	—	—
(Sedges)																
40. *Centaurea cyanus* (A)	Sd	MS	S	MS	S	MS	S	—		—		—		—	S	—
(Cornflower)	Yp	MR	MS	MR	MS	MR	MS								MR	
41. *Centaurea nigra* (P)		—	MS	—	MS	—	MS*	—		—		—		—	—	—
(Knapweed)																
42. *Centaurea scabiosa* (P)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
(Greater knapweed)																
43. *Cerastium arvense* (P)		—	R	—	R	—	R	—		—		—		—	—	—
(Field mouse-ear chickweed)																
44. *Cerastium glomeratum* (A)		—		S		S		—		—		MR		—	—	—
(Sticky mouse-ear chickweed)																
45. *Cerastium vulgatum*	Sd	MR	MS	MR	MS	MR	MS	—		—		MS		MS	R	R
(A or P)	Yp	R	MR	R	MR	R	MR							MR		
(Mouse-ear chickweed)																

46. *Chaenorrhinum minus* (A) (Small toadflax)		—		—		—		—		—		MR		—	—	—
47. *Chaerophyllum temulum* (B) (Royal chervill)		—		—		—		—		—		—		—	—	—
48. *Chamaenerion angustifolium* (P) (Rosebay willow-herb)		—	R	—	MR	—	MR*	—		—		—		—	—	—
49. *Chenopodium album* (A)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
(Fat hen)	Yp	S	S	S	S	S	S	MS	S	MS	S	S	S	S	MR	MR
50. *Chrysanthemum leucanthemum* (P) (Ox-eye daisy)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
51. *Chrysanthemum segetum* (A)	Sd	R		R		R	MR	R		R		R		MR	S(w)	S
(Corn marigold)	Yp					R	R							R	MR(w)	R
52. *Cichorium intybus* (P) (Chicory)	Yp	S		S		S		R		MR		—		S	—	—
53. *Cirsium acaule* (P) (Stemless thistle)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
54. *Cirsium arvense* (P)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	S	—	—
(Creeping thistle)	SK	MS	S	MS	S	MS	S	MS	S	MS	S	MS	S	S	—	—
	LTCA	MR	MS	MR	MS	MR	MS	MR	MS	MR	MR	MR	MS	MS	—	—
	LTCG	—	MR	—	MR	—	MR	—	MR	—	MR	—		—	—	—
55. *Cirsium vulgare* (B)	Sd	S	S	S	S	S	S	S	S	S	S	—		—	—	—
(Spear thistle)	SK	S	S	S	S	S	S	S	S	MS	S	—		—	—	—
	LTC	MS	S	MS	S	MS	S	MS	S	MS	S	—		—	—	—
56. *Claytonia perfoliata* (A)		—		—		—		—		—		—		—	—	—
57. *Colchicum autumnale* (P) (Autumn crocus)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
58. *Conium maculatum* (B)	Yp	—		—		—	MS*	—		—		—		—	—	—
(Hemlock)	LTC	—		—		—	MS*									
59. *Conopodium majus* (P) (Pignut)		R		R		R		—		—		—		—	—	—
60. *Convolvulus arvensis* (P)	SK	MS	S	MS	S	MS	S	MS	S	MS	S	R		MS	—	—
(Field bindweed)	LTC	R	MR	R	MR	R	MR	R	MR	R	MR					
61. *Coronopus didymus* (A) (Lesser swine-cress)		S		S		S		MS		S		—		S	—	—
62. *Coronopus squamatus* (A or B) (Swine-cress)		MR		MR		—		MR		MR		S		—	—	—

TABLE II (*continued*)

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Weed / Chemical and dose; oz. acid equivalent per acre.		MCPA-salt		2,4-D -amine		2,4-D -ester		MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/2,3,6-TBA	DNOC	Dinoseb
		12	14	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
63. *Crepis biennis* (B) (Rough hawk's beard)		—	S	—	S	—	S*	—		—		—		—	—	—
64. *Crepis capillaris* (A) (Smooth hawk's beard)		—		MS		—		—		—		—		MS	—	—
65. *Cuscuta epithymum* (A) (Common dodder)		—		—		—		—		—		—		—	—	—
66. *Datura stramonium* (A) (Thorn apple)		MS		MS		MS		MR		MS		—		MS	—	—
67. *Daucus carota* (B) (Wild carrot)		—	MR	—	MR	—	MR	—	R	—	MR	MR		MR	—	—
68. *Descurainia sophia* (A) (Flixweed)		S		S		S		—		—		—		—	—	—
69. *Echium vulgare* (B) (Viper's bugloss)	Sd	MR		MR		MR		—		—		—		MS	—	—
	Yp													MR		
70. *Epilobium spp.* (P) (Willow herb)		MR		MR		MR		R		R		—		MS	—	—
71. *Equisetum arvense* (P) (Horsetail)	SK	MS	S	MS	S	MS	S	MS	S	MS	S	R		S	—	—
	LTC	R	R	R	R	R	R	R	R	R	R			—		
72. *Equisetum palustre* (P) (Marsh horsetail)	SK	S	S	S	S	MS	S	S	S	S	S					
	LTC	R	R	R	R	R	R	R	R	R	R	—		—	—	—
73. *Erigeron canadensis* (A) (Canadian fleabane)		S		S		S		—		—		—		—	—	—
74. *Erodium cicutarium* (A) (Common storksbill)		MR		MR		MR		—		—		—		—	—	—
75. *Erysimum cheiranthoides* (A) (Treacle mustard)	Sd	S	S	S	S	S	S	MS	S	MS	S	—		S	S	S
	Yp	S	S	S	S	S	S	MR	MS	MR	MS			S	S	S
76. *Euphorbia exigua* (A) (Dwarf spurge)		—		—		—		—		—		—		—	—	—

77. *Euphorbia helioscopia* (A) (Sun spurge)		MS	MR	MR	—	—	—	—	MR	MR
78. *Euphorbia peplus* (A) (Petty spurge)		MR	R	R	—	—	—	—	—	—
79. *Filipendula ulmaria* (P) (Meadow sweet)		— MR	— MR	— MR*	R	R	—	—	—	—
80. *Fumaria officinalis* (A) (Fumitory)	Sd Yp	MS S R MR	MR MS R MR	MR MS R MR	S S MR MR	MS S R MR	MS S MR MS	S MR	S(w) S(w)	S MS
81. *Galeopsis speciosa* (A) (Large-flowered hempnettle)		S	MS	MS	—	—	—	S	—	MS
82. *Galeopsis tetrahit* (A) (Common hempnettle)	Sd Yp	MS S MR MS	R MR R R	R MR R R	MS MS MR MR	R MR R R	R MS R MR	S MS	S S	S MS
83. *Galinsoga parviflora* (A) (Gallant soldier)		S	S	S	—	—	—	S	—	—
84. *Galium aparine* (A) (Cleavers)	Sd Yp	R	R	R	R	R	MS S MS S	S MS	S MS	S MS
85. *Galium hercynicum* (P) (Heath bedstraw)		— MR	—	— MR	—	—	—	—	—	—
86. *Galium mollugo* (P) (Hedge bedstraw)		—	—	—	—	—	—	—	—	—
87. *Galium verum* (P) (Ladies bedstraw)		R	R	R*	R	R	—	—	—	—
88. *Geranium dissectum* (A) (Cut-leaved cranesbill)		MR	MR	MR	—	—	—	MR	—	—
89. *Geranium molle* (A) (Dove's foot cranesbill)		MR	MR	MR	—	—	MS	MR	MR	—
90. *Geranium pratense* (P) (Meadow cranesbill)		— MR	— MR	— MR*	—	—	—	—	—	—
91. *Geranium pusillum* (A) (Small-flowered cranesbill)		—	—	—	—	—	—	—	—	—
92. *Gnaphalium uliginosum* (A) (Marsh cudweed)		—	—	—	R	—	—	—	—	—
93. *Heracleum sphondylium* (P) (Hogweed)		— MR	— MR	— MR	—	—	—	—	—	—

Table II (*continued*)

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Chemical and dose ; oz. acid equivalent per acre.	MCPA-salt		2,4-D				MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/2,3,6-TBA	DNOC	Dinoseb
			-amine		-ester										
Weed	12	14	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
94. *Hieracium pilosella* (P) (Mouse-ear hawkweed)	—	MS	—	MS	—	S*	—		—		—		—	—	—
95. *Holcus lanatus* (P) (Yorkshire fog)	R		R		R		R		R		R		R	—	—
96. *Holcus mollis* (P) (Creeping softgrass)	R		R		R		R		R		R		R	—	—
97. *Hyoscyamus niger* (A or B) (Henbane)	—	MR	—	MR	—	MR	—		—		—		—	—	—
98. *Hypericum perforatum* (P) (Common St. John's wort)	—	MR	—	MR	—	MR	—		—		—		—	—	—
99. *Hypochaeris radicata* (P) (Cat's ear)	—	MS	—	MS	—	S*	—		—		—		—	—	—
100. *Iris pseudacorus* (P) (Yellow flag)	—	MR	—	MR	—	MR*	—	R	—	R	—		—	—	—
101. *Juncus acutiflorus* (P) (Sharp-flowered rush)	—		—		—		—		—		—		—	—	—
102. *Juncus articulatus* (P) (Jointed rush)	R		R		R		R		R		—		—	—	—
103. *Juncus conglomeratus* (P)	—	MS	—		—		—	MS	—	MS	—		—	—	—
104. *Juncus effusus* (P) Sd	S	S	S	S	S	S	MS	S	—		—			—	—
(Soft rush) SK	MS	S	MS	S	MS	S*	MS	S	—		—		S	—	—
LTC	—	MS	—	MS	—	MS*	—	MR	—	MR	—			—	—
105. *Juncus inflexus* (P) (Hard rush)	—	MR	R		R		R		—		—		—	—	—
106. *Juncus maritimus* (P) (Sea rush)	—	MR	—	MR	—	MR*	—		—		—		—	—	—
107. *Juncus squarrosus* (P) (Heath rush)	R		R		—	MR*	R		R		—		—	—	—
108. *Juncus subnodulosus* (P) (Blunt-flowered rush)	—		R		—		—		—		—		—	—	—

109. *Knautia arvensis* (P) (Field scabious)		—	MS	—	MS	—	MS	—		—		MR		—	—	—
110. *Lamium album* (P) (White deadnettle)		—	R	—	R	—		—		—		—		—	—	—
111. *Lamium amplexicaule* (A)	Sd	MR	MS	R	MR	R	MR	R		R		R		MS	—	—
(Henbit)	Yp	R	R	R	R	R	R							R		
112. *Lamium purpureum* (A) (Red deadnettle)		MR		MR		R		R		—		R		MR	—	—
113. *Lapsana communis* (A) (Nipplewort)		R		R		R		R		R		—		R	—	—
114. *Leontodon autumnalis* (P) (Autumnal hawkbit)		—	MS	—	S	—	S*	—	MS	MS	S	—		—	—	—
115. *Leontodon hispidus* (P) (Rough hawkbit)		—	MR	—	MS	—	—	—		—		—		—	—	—
116. *Linaria vulgaris* (P) (Toadflax)		—	R	—	R	—	R*	—		—		—		—	—	—
117. *Lithospermum arvense* (A)	Sd	MR	MS	MR	MS	MR	MS	—		—		—		MS	S	S
(Corn gromwell)	Yp	R	MR	R	MR	R	MR							MR	S	S
118. *Lotus corniculatus* (P) (Birdsfoot trefoil)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
119. *Luzula campestris* (P) (Field woodrush)		R		R		R		R		R		—		—	—	—
120. *Lycopsis arvensis* (A or B) (Bugloss)		MR		MR		MR		—		—		—		MS	—	—
121. *Lythrum salicaria* (P) (Purple loosestrife)		—		—	MS	—	MS	—		—		—		—	—	—
122. *Matricaria chamomilla* (A)	Sd	R		R		R		R		R		R		MS	S	S
(Wild chamomile)	Yp													MR	MR	MR
123. *Matricaria maritima*	Sd	R	MR	R	MR	R	MR	R		R		MR	MS	MS	S	S
spp. inodora (A) (Scentless mayweed)	Yp	R	R	R	R	R	R					R	MR	MR	S	MR
124. *Matricaria*	Sd	R		R		R		R		R		R		MS	—	—
matricarioides (A) (Pineapple weed)	Yp													MR		
125. *Medicago lupulina* (A or P) (Black medick)		MR		MR		MR		R		—		MR		S	—	—

Table II (*continued*)

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Weed / Chemical and dose; oz. acid equivalent per acre.		MCPA-salt		2,4-D -amine		2,4-D -ester		MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/ 2,3,6-TBA	DNOC	Dinoseb
		12	24	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
126. *Melandrium album* (A, B or P) (White campion)	Sd	R		R		R		R		—		MS		S	—	—
	Yp													MS		
127. *Melandrium noctiflorum* (A) (Night-flowering campion)		—		R		R		—		—		—		—	—	—
128. *Melandrium rubrum* (B or P) (Red campion)		R		R		R		—		—		MS		—	—	—
129. *Mentha arvensis* (P) (Corn mint)		MR		MR		MR		R		R		MR		R	—	—
130. *Myosotis arvensis* (A) (Common forget-me-not)		MS		MS		MS		MR		R		R		MS	—	S
131. *Odontites verna* (A) (Red bartsia)		MS		MS		—		R		—		—		—	—	—
132. *Oenanthe crocata* (P) (Hemlock water dropwort)		—		—		—		—		—		—		—	—	—
133. *Ononis repens* (P) (Restharrow)		—		—		—		—		—		—		—	—	—
134. *Orobanche minor* (A) (Lesser broom-rape)		—		—		—		—		—		—		—	—	—
135. *Oxalis spp.* (P)		R		R		R		R		R		—		—	—	—
136. *Papaver argemone* (A) (Long prickly-headed poppy)		—		—		—		—		—		—		—	—	—
137. *Papaver dubium* (A) (Long-headed poppy)		—		—		—		—		—		—		—	—	—
138. *Papaver rhoeas* (A) (Corn poppy)	Sd	MS	S	MS	S	MS	S	MS	S	MS	S	MS	S	MS	S	S
	Yp	MR	MS	MR	MS	MS	S	R	MR	R	MR	MR	MS	MR	S	MR

139. *Petasites hybridus* (P) (Butterbur)		R		MR		MR*		—		—		—		—	—	—
140. *Picris echioides* (A or B) (Bristly ox-tongue)		—		MS		MS		—		—		—		—	—	—
141. *Plantago coronopus* (A, B or P) (Starweed)		MS		MS		S		—		—		—		MS	—	—
142. *Plantago lanceolata* (P)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
(Ribwort)	SK	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
	LTC	S	S	S	S	S	S	S	S	S	S	MS	MS	—	—	—
143. *Plantago major* (P)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
(Greater plantain)	SK	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
	LTC	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
144. *Plantago media* (P)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
(Hoary plantain)	SK	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
	LTC	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
145. *Polygonum amphibium* (P) (Amphibious bistort)		MR		MR		MR		—		—		—		—	—	—
146. *Polygonum aviculare* (A)	Sd	R	MR	MR	S	MR	S	MR	MR	MR	MS	R	MR	MS	S	S
(Knotgrass)	Yp	R	R	R	MR	R	MS	R	R	R	MR	R	R	MR	R	R
147. *Polygonum bistorta* (P) (Bistort)		R		R		R		R		R		—		—	—	—
148. *Polygonum convolvulus* (A)	Sd	R	MR	MR	MS	MR	MS	R	MR	MR	MS	R	MR	MS	S	S
(Black bindweed)	Yp	R	R	R	MR	R	MR	R	R	R	MR	R	R	MR	MS	R
149. *Polygonum*	Sd	R	MR	MR	MS	MR	MS	R	MR	MS	S	MS	S	MS	S	S
lapathifolium (A) (Pale persicaria)	Yp	R	R	R	MR	R	MR	R	R	MR	MS	MR	MS	MR	R	R
150. *Polygonum persicaria* (A)	Sd	R	MR	MR	MS	MR	MS	R	MR	MS	S	R	MR	S–MS	S	S
(Redshank)	Yp	R	R	R	MR	R	MR	R	R	MR	MS	R	R	MR	R	R
151. *Potentilla anserina* (P) (Silverweed)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
152. *Potentilla reptans* (P) (Cinquefoil)		R		R		R		—		—		—		—	—	—
153. *Pteridium aquilinum* (P) (Bracken)		R		R		R		R		R		R		—	—	—
154. *Pulicaria dysenterica* (P) (Fleabane)		—	MS	—	MS	—		—		—		—		—	—	—

TABLE II (*continued*)

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Weed	Chemical and dose ; oz. acid equivalent per acre.	MCPA-salt		2,4-D -amine		2,4-D -ester		MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/2,3,6-TBA	DNOC	Dinoseb
		12	24	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
155. *Ranunculus acris* (P)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
(Crowfoot)	SK	MS	S	MS	S	MS	S	MS	S	MS	S	MS	S	—	—	—
	LTC	MS	S	MS	S	MS	S	MS	S	MR	MS	MR	MS	—	—	—
156. *Ranunculus arvensis* (A)	Sd	S	S	S	S	S	S	S	S	S	S	—	S	S	S	S
(Corn buttercup)	Yp	MS	S	MS	S	MS	S	MS	S	S	S	—	MS	S	R	R
157. *Ranunculus bulbosus* (P)	Sd	S	S	S	S	S	S	S	S	S	S	—		—	—	—
(Bulbous buttercup)	SK	MS	S	MS	S	MS	S	MS	S	MS	S	—		—	—	—
	LTC	R	MR	R	MR	R	MR*	R	MR	R	MR	—		—	—	—
158. *Ranunculus repens* (P)	Sd	S	S	S	S	S	S	S	S	S	S	S	S	—	—	—
(Creeping	SK	S	S	S	S	S	S	S	S	S	S	MS	S	—	—	—
buttercup)	LTC	MS	S	MS	S	MS	S*	MS	S	MS	S	MR	MS	—	—	—
159. *Ranunculus sardous* (A)		S		S		S		S		—		—		S	—	—
(Hairy buttercup)																
160. *Raphanus raphanistrum* (A)	Sd	S	S	S	S	S	S	R	MR	R		S	S	S	S	S
(Wild radish)	Yp	MS	S	MS	S	MS	S	R	R			S	S	S	S	MR
161. *Rhinanthus minor* (A)		MR		MR		R		—		—		—		MR	—	—
(Yellow rattle)																
162. *Rorippa sylvestris* (P)		—		—		—		—		—		—		—	—	—
(Creeping yellow-cress)																
163. *Rumex acetosa* (P)	Sd	—		—		—		—		—		—		—	—	—
(Sorrel)	SK	MS		MS		MS		—		—		—		—	—	—
	LTC	MR		MR		MR*		—		—		R		—	—	—
164. *Rumex acetosella* (P)	Sd	—		—		—		—		—		—		—	—	—
(Sheep's sorrel)	SK	MS		MS		MS		—		—		—		—	—	—
	LTC	MR		MR		MR*		—		—		R		—	—	—
165. *Rumex conglomeratus* (B or P)		—		—		—		—		—		—		—	—	—
(Sharp dock)																

166. *Rumex crispus* (P)	Sd	S	S	S	S	MS	S	S	S	S	S	—	S	S	—	—
(Curled dock)	SK	S	S	S	S	MR	MS	MS	S	MS	S	—	MS	S	—	—
	LTCA	MS	S	MS	S	MR	MS	MR	MS	MR	MS	MR	MS	MR	—	—
	LTCG	—	MS	—	MS	—	MS*	—	MS	—	MS	—	—	—	—	—
167. *Rumex obtusifolius* (P)	Sd	S	S	S	S	MS	S	S	S	S	S	—	S	S	—	—
(Broad-leaved dock)	SK	S	S	S	S	MR	MS	MR	MS	MR	MS	—	S	S	—	—
	LTCA	MR	S	MR	S	R	MR	R	MR	R	MR	—	MS	—	—	—
	LTCG	—	MR	—	MR	—	MS*	—	R	—	R	—	—	—	—	—
168. *Scandix pecten-veneris* (A)	Sd	MR	MS	MR	MS	R	MR	R		R		—		MS	S	S
(Shepherd's needle)	Yp	R	R	R	R	R	R							R	MR	MR
169. *Scleranthus annuus* (A or B) (Annual knawel)		MS		MS		MR		—		—		—		MS	S	S
170. *Senecio aquaticus* (B) (Marsh ragwort)		—	MS	—	MS	—	MS*	—		—		—		—	—	—
171. *Senecio jacobaea* (B or P) (Ragwort)		MS		MS		MS		R		R		—		—	—	—
172. *Senecio squalidus* (A) (Oxford ragwort)		—		—		—		—		—		—		—	—	—
173. *Senecio viscosus* (A) (Stinking groundsel)		—		—		—		—		—		—		—	—	—
174. *Senecio vulgaris* (A)	Sd	MR	MS	MR	MS	MR	MS	R		MR	MS	MS	MS	MS	S	S
(Groundsel)	Yp	R	R	R	R	R	R			R	R	MR	MR	R	MR	MR
175. *Sherardia arvensis* (A) (Field madder)		—		—		—		R		—		—		—	—	—
176. *Silene cucubalus* (P) (Bladder campion)		R		R		R		R		—		MS		—	—	—
177. *Sinapis alba* (A)	Sd	S	S	S	S	S	S	MS	S	MS	S	—	S	S	S	S
(White mustard)	Yp	S	S	S	S	S	S	MR	MS	MR	MS	—	S	S	S	S
178. *Sinapis arvensis* (A)	Sd	S	S	S	S	S	S	MS	S	MS	S	S	S	S	S	S
(Charlock)	Yp	S	S	S	S	S	S	MS	MS	MR	S	MS	S	S	S	S
179. *Sisymbrium officinale* (A) (Hedge mustard)		S		S		S		—		—		—		S	—	—
180. *Solanum dulcamara* (P) (Woody nightshade)		—	MR	—	MR	—	MR*	—		—		—		—	—	—
181. *Solanum nigrum* (A)	Sd	MR	MS	MR	MS	R	MR	—		—		MS		MS	S	S
(Black nightshade)	Yp	R	R	R	R	R	R					MR		MR	R	R

Table II (*continued*)

THE RESPONSE OF WEEDS TO SOME HERBICIDES USED IN AGRICULTURAL CROPS

Weed	Chemical and dose ; oz. acid equivalent per acre.	MCPA-salt		2,4-D -amine		2,4-D -ester		MCPB-sodium		2,4-DB-sodium		Mecoprop-salt		MCPA/ 2,3,6-TBA	DNOC	Dinoseb
		12	21	10	20	5	10	24	32	24	32	32†	40†	12 + 4	(i)	(ii)
182. *Sonchus arvensis* (P)	Sd	—		—		—		—		—		—		—	—	—
(Perennial sowthistle)	SK	MR	MS	MR	MS	MR	MS	MR	MS	MR	MS	MR		—	—	—
	LTC	R	MR	R	MR	R	MR	—	—	—	—	—		—	—	—
183. *Sonchus asper* (A)	Sd	MS	S	MS	S	MS	S	MS	S	MS	S	MS		S	S	S
(Spiny sowthistle)	Yp	MR	MS	MR	MS	MR	MS	MR	MS	MR	MS			MS	R	MR
184. *Sonchus oleraceus* (A)	Sd	MS	S	MS	S	MS	S	MS	S	MS	S	MR	MS	S	S	S
(Annual sowthistle)	Yp	MR	MS	MR	MS	MR	MS	MR	MS	MR	MS	MR	MR	MS	R	MR
185. *Specularia hybrida* (A)		MS		MR		—		—		—		—		MS	—	—
(Venus's looking-glass)																
186. *Spergula arvensis* (A)	Sd	MR	MS	MR	MS	R	MR	R		R		R	MR	MS	S	MS
(Corn spurrey)	Yp	R	R	R	R	R	R					R	R	MR	MR	MR
187. *Stellaria media* (A)	Sd	MR	MS	MR	MS	R	MR	R		R		S	S	S–MS	S	S
(Chickweed)	Yp	R	R	R	R	R	R					S	S	MR	S	S
188. *Symphytum officinale* (P)		—	MR	—	MR	—	MR**	R		R		—		—	—	—
(Comfrey)																
189. *Tanacetum vulgare* (P)		—	MR	—	MR	—	MR**	—		—		—		—	—	—
(Tansy)																
190. *Taraxacum officinale* (P)	Sd	MR	MS	MS	S	MS	S									
(Dandelion)	SK	MR	MS	MS	S	MS	S	R		MR		MR		—	—	—
	LTC	R	MR	MR	MS	MR	MS									
191. *Thlaspi arvense* (A)	Sd	S	S	S	S	S	S	S	S	—		S	S	S	S	S
(Field pennycress)	Yp	S	S	S	S	S	S	MS	MS			MS	MS	S	S	S
192. *Tragopogon pratensis*		MS		MS		MS		—		—		—		—	—	—
(A, B or P)																
(Goat's beard)																
193. *Tussilago farfara* (P)	SK	MR	MS	MR	MS	MR	MS	—		—		R		MS	—	—
(Coltsfoot)	LTC	R	MR	R	MR	R	MR									
194. *Urtica dioica* (P)	Sd	MS	S	MS	S	MS	S	MS	S	—		MS	S	—	—	—
(Stinging nettle)	SK	MS	S	MS	S	MS	S	MS	S	—		MS	S	—	—	—
	LTC	R	MR	R	MR	R	MR	R	MR	—		—	—	—	—	—

195. *Urtica urens* (A)	Sd	MS	S	S	S	MS	S	S	S	S	S	S	S	S	S	S
(Annual nettle)	Yp	MR	MS	MS	S	MR	MS	MS	MS	MS	S	—	S	S	MR	MR
196. *Valerianella locusta* (A) (Lamb's lettuce)		—		—		—		—		—		—		—	—	—
197. *Veronica agrestis* (A)	Sd	MR	MS	MR	MS	R	MR	R		R		R		MS	S	S
(Procumbent speedwell)	Yp	R	R	R	R	R	R							R	S	MR
198. *Veronica anagallis-aquatica* (P or A) (Water speedwell)		—		—		—		—		—		—		—	—	—
199. *Veronica arvensis* (A)	Sd	MR		MR		MR		—		—		MR		MR	S	S
(Wall speedwell)	Yp															MR
200. *Veronica chamaedrys* (P) (Germander speedwell)		MR		MR		MR		—		—		R		—	—	—
201. *Veronica hederifolia* (A)	Sd	MR	MS	MR	MS	R	MR	R		R		—		MS	S	S
(Ivy-leaved speedwell)	Yp	R	R	R	R	R	R							R	S	MR
202. *Veronica persica* (A)	Sd	MR	MS	MR	MS	R	MR	MR	MS	R	MR	MR		MS	S	S
(Buxbaum's speedwell)	Yp	R	R	R	R	R	R	R	R	R	R			R	S	MR
203. *Veronica serpyllifolia* (P) (Thyme-leaved speedwell)		MR		MR		MR		—		—		—		—	—	—
204. *Vicia cracca* (P) (Tufted vetch)		MS		MS		MS		—		—		—		MS	—	—
205. *Vicia hirsuta* (A)	Sd	S		S		S		—		—		—		S	S	—
(Hairy tare)	Yp														R	
206. *Vicia sativa* (A) (Common vetch)		MS		MS		MS		—		—		—	S	MS	—	—
207. *Viola arvensis* (A)	Sd	MR	MS	MR	MS	MR	MS	MR		MR		R		MS	—	MS
(Field pansy)	Yp	R	R	R	R	R	R							R	—	MR
208. *Viola tricolor* (A)	Sd	MS	S	MR	MS	MR	MS	MR		MR		R		MR	S	S
(Heart's ease)	Yp	R	MR	R	R	R	MR							—	R	R
209. *Xanthium spinosum* (Spiny cocklebur)		S		S		S		—		—		—		—	—	—

CONTROL OF WEEDS OF SPECIAL IMPORTANCE.

Cardaria draba. Hoary pepperwort cannot be eradicated by a single treatment with MCPA or 2,4-D but well over 90 per cent control can be obtained by treatment in a winter cereal in two successive seasons. If this is done, MCPA and 2,4-D are equally effective and should be applied at 12–16 oz. per acre during the period after the shoots are a few inches high up to the flowering stage. To ensure eradication of the weed after two years' spraying, it is advisable to plant a spring cereal or other crop resistant to MCPA and 2,4-D in the third year so that a spray treatment can again be made if a few remaining shoots appear. If only a single year's treatment can be made, the rate of application should be increased up to 32 oz. per acre according to formulation and crop, and MCPA used in preference to 2,4-D if treatment is made shortly after the pepperwort shoots have emerged. If the weed is treated at the flowering stage, MCPA and 2,4-D are equally effective.

Cirsium arvense. Creeping thistle spreads rapidly by means of brittle roots which will readily produce new shoots or remain dormant for a number of years if buried under a vigorous sward. If cutting is carried out regularly over a number of years when the thistle is in the bud stage some control is achieved, but chemical control is much more satisfactory.

The shoots of creeping thistle are readily killed by MCPA, 2,4-D, MCPB and 2,4-DB, and provided the application is made at the correct time (i.e. at the early bud stage), a considerable control of the root system will also result. The best results are frequently obtained by spraying reseeded grassland in the year after sowing, the root system of the weed having been broken up by the previous cultivations. MCPB and 2,4-DB are particularly useful for this.

The following dosage rates are suggested : (*a*) MCPA and 2,4-D at 16–24 oz. per acre for shoot kill in an arable crop ; 24–32 oz. per acre for grassland ; (*b*) MCPB and 2,4-DB at 24–32 oz. per acre for shoot kill or for long-term control ; (*c*) mecoprop at 40 oz. per acre for shoot kill and appreciable root kill in an arable crop.

Equisetum spp. The two most important weed species of horsetail are *E. arvense* and *E. palustre.* The shoots of both species are readily killed by MCPA and 2,4-D, but there is generally strong regrowth from the underground rhizomes the year following treatment. For *E. arvense* a partial " kill " of the root system may be obtained by a single application ; for *E. palustre* a single application is unlikely to produce any permanent effect. In general, the aerial shoots should be treated when they have made maximum growth. The following rates are suggested : (*a*) for kill of aerial shoots only, 12–20 oz. MCPA or 2,4-D per acre ; (*b*) for kill of aerial shoots and for partial suppression of regrowth, 32 oz. MCPA or 2,4-D per acre. For the control of *E. palustre* in grassland required for hay or silage, MCPA or 2,4-D applied a week or more before the grass is to be cut will successfully kill *Equisetum* shoots, thus allowing a hay crop to be taken.

Juncus spp. There are many species of rush occurring in Great Britain but only one, *Juncus effusus,* the common rush, has so far been found to be readily killed by MCPA and 2,4-D. *J. conglomeratus* is closely allied to *J. effusus,* but no information is available regarding the effect of herbicides. Other rush species which are important as weeds but which appear to be resistant to these materials are *J. articulatus, J. inflexus* and *J. squarrosus. J. effusus* can be controlled by medium, high or low volume spray applications of MCPA (salt), 2,4-D (amine) at 32 oz. per acre and 2,4-D (ester) at 16 oz. per acre. The treatment should be applied preferably just before the rush flowers. Good results are obtained with or without cutting but a cut one month after treatment not only improves the kill obtained but helps towards the more rapid development of a useful sward by encouraging grass establishment in the old rush clumps. If desired, rushes may be cut a month before the spray treatment with equally effective results. Cutting at the time of spraying is not recommended. For the permanent eradication of rushes, spraying must often by followed by measures, e.g. liming, draining, which will improve the sward and help to prevent reinfestation by seedlings.

Ranunculus spp. Creeping buttercup *R. repens*, crowfoot *R. acris* and bulbous buttercup *R. bulbosus* are the most important species. As each species differs in its reaction towards MCPA and 2,4-D it is important to identify the type of buttercup correctly before treatment. Creeping buttercup is easily controlled by MCPA or 2,4-D, the former being more effective. The best time for treatment is in spring or early summer up to flowering, during which time 12–24 oz. per acre are recommended. Successful treatment may however be made at any time of the year during active growth of the weed, but the rate of application should be increased to 24–32 oz. per acre. Crowfoot is slightly less susceptible than creeping buttercup. The recommendations for treatment are similar. Bulbous buttercup is much more resistant than the other species. Treatment in spring will usually prevent flowering the same season but is unlikely to result in a significant reduction in population the year after treatment.

Senecio jacobaea. The most common method for the control of ragwort is the cutting of the flowering shoots when in full flower. Provided these shoots are removed from the field seeding is prevented, but even though the plant is normally a biennial the cut plants may continue to grow into the next year. Grazing by old ewes for short periods will also help to control ragwort, but the most effective method of cultural control is to plough and put the field through an arable rotation. On much of the land infested with ragwort, ploughing is not possible and spraying must be carried out.

MCPA-salt and 2,4-D-amine at 24–32 oz. per acre or 2,4-D-ester at 16–24 oz. per acre will normally kill ragwort in all stages of growth ; 2,4-D generally giving better results than MCPA. A single treatment is usually insufficient for complete control and a programme of spraying should be carried out to prevent reinfestation. Probably the best time for spraying is in June when the flowering shoots are developing rapidly and the seedling and rosette plants are actively growing.

Taraxacum officinale. The best time to treat dandelion with MCPA or 2,4-D is in spring when at the flower bud stage, but good results may be obtained at any time provided the weed is growing strongly. 2,4-D gives more consistent results than MCPA. Rates of application recommended are : 2,4-D amine 16–24 oz. per acre, 2,4-D ester 16 oz. per acre, MCPA-salt 32 oz. per acre. It is resistant to MCPB.

Rumex spp. The two most important species of dock are *R. crispus* (Curled dock) and *R. obtusifolius* (Broad-leaved dock). Both species are easily controlled in the seedling stage by MCPA, 2,4-D, MCPB and 2,4-DB. Established plants are very difficult to kill ; the flowering shoots are frequently checked and seeding reduced by spraying in cereal crops, but broad-leaved dock may be completely resistant when well established in grassland. Spraying regrowth after cutting frequently gives better results than the spraying of the established plant.

Recommended doses are : (*a*) seedlings and regrowing root-stocks in cereals—*R. crispus* : MCPA-salt, 2,4-D-amine 16–24 oz. ; MCPB, 2,4-DB 32–48 oz. ; 2,4-D-ester 16 oz. per acre ; *R. obtusifolius* : MCPA-salt, 2,4-D-amine 24–32 oz. ; MCPB, 2,4-DB 32–48 oz. ; 2,4-D-ester 16 oz. per acre. Mecoprop at 32 oz. per acre has also given reasonable control in cereals. (*b*) Established plants in grassland—*R. crispus* : MCPA, 2,4-D-amine 24–32 oz. ; MCPB, 2,4-DB 32–48 oz. ; 2,4-D-ester 16–24 oz. per acre ; *R. obtusifolius* : resistant.

Agropyron, Agrostis spp. Three common varieties of perennial weed grasses with a creeping root-stock are commonly known as " couch " or " twitch ". These are the true couch (*Agropyron repens*), common bent grass (*Agrostis gigantea*) and creeping bent grass (*Agrostis stolonifera*).

Until recently the control of these weed grasses has been mainly dependent on a successful summer fallow. This method is extremely effective in a dry season and under suitable soil conditions, but is liable to be unsatisfactory in wet seasons. A programme of rotary cultivations has been successful even in wet seasons, and may be carried out during the early spring or autumn as well as during the summer, thus avoiding the necessity of a fallow. The first rotovation must be deep with the tractor slowly moving forward and a high rotor speed. This ensures maximum fragmentation of the root-stocks ; the resulting fragments are then killed by a process of exhaustion, as the buds are stimulated to grow and the shoots then destroyed by subsequent rotary cultivations. These subsequent cultivations should be carried out whenever the new shoots appear above the ground and the ground greens over. The number of cultivations required will vary from two to five or six depending on soil and weather conditions. The important features of this method are to obtain maximum fragmentation of the root-stocks with the initial rotovation and to ensure that this first cultivation is to the full depth of the couch.

On deep soils deep ploughing properly carried out will control an infestation, provided the couch is buried at least 9 in. deep and left undisturbed by any following cultivations.

Couch can now also be controlled by chemical methods, in particular trichloroacetic acid (TCA), amino triazole and dalapon. TCA is taken up through the roots, and cultivations before spraying should be carried out to bring the maximum number of rhizomes into the surface layers. The chemical should be sprayed on to bare soil, two applications of 20 lb. per acre being applied to heavy soils in the autumn with a 4–6 week interval between sprayings. On light soils a single application of 30 lb. per acre, or two applications of 15 lb. per acre, should be given, better results being obtained by spring applications. Control of couch is enhanced if the spraying is carried out under moist soil conditions, and if one or two cultivations follow the spray treatments. The persistence of TCA in the soil varies with soil type and rainfall conditions and subsequent cropping must be carefully planned. Potatoes, kale and turnips are fairly resistant to TCA and may be planted one month after treatment ; for peas, beans and sugar beet an interval of two months must be allowed before sowing. Under no circumstances should cereals be planted in the same autumn after autumn treatment, nor in the same spring following spring treatment.

Amino triazole and dalapon, in contrast, should be applied to the leaves of actively growing couch. Treatment is usually carried out in the early autumn or when the couch starts to grow actively in the spring. Amino triazole should be applied at rates of 4–8 lb. per acre of activated material. At dosage rates recommended by manufacturers the subsequent crop can be sown following ploughing 2–3 weeks after spraying. The rate of application for dalapon is generally 10–15 lb. per acre, though higher rates may be required under certain circumstances. Efficient ploughing should follow 2–3 weeks after spraying. Sufficient time must then elapse to allow the dalapon to be broken down in the soil before the sowing of the next crop. Again, cereals should not be sown in the autumn following autumn treatment or in the spring after a spring application. Other crops can generally be planted after an interval of 6–8 weeks.

Chemical control can be made more effective by the careful planning of the subsequent cropping. Root crops which can be inter-row cultivated will improve the control ; alternatively a competitive crop such as kale in good growing conditions may smother any remaining shoots.

Avena spp. There are two species of wild oat, the common one, *Avena fatua*, which germinates mainly in the spring ; and the winter germinating species, *A. ludoviciana*. The most common source of infestation into clean land in the past has been contaminated seed corn. The germinating seedlings can be easily controlled by cultivations, provided the dormancy of the seed can be broken. Stubble cleaning will help to encourage germination in the autumn and winter, and combined with a succession of spring crops sown after March, *A. ludoviciana* can be reasonably well controlled. On the other hand the main germinating period of *A. fatua* is during late March and early April. Recently it has been shown that the preparation of a seedbed early in March and delayed drilling of the cereal crop for four or five weeks, will encourage germination and give an opportunity to kill the seedlings by cultivation. There is a slight reduction in yield of the cereal crop, but where this procedure can be followed for two years in succession up to 90 per cent control of the wild oats has been achieved. On suitable soil types a wide rotation may be possible and a high proportion of row crops grown to allow hoeing. This type of rotation combined with a long ley can considerably reduce the wild oat infestation.

Chemical methods of wild oat control in wheat and barley have recently been introduced but have not reached the stage where definite recommendations for their use can be made. The use of barban as a post-emergence spray when the wild oats are in the 1–2½ leaf stage has been successful under certain conditions, whilst a pre-sowing application of di-allate has given equally promising results. Certain varieties of corn are extremely sensitive to these chemicals and must not be sprayed ; generally speaking barban is safer on spring wheat than on spring barley, in contrast to di-allate where the reverse is true.

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